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Anemia and student's educational performance in rural Central China: Prevalence, correlates and impacts

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ABSTRACT

Anemia in children impairs physical growth and cognitive development, reducing their overall human capital accumulation. While much research has been conducted on anemia prevalence in the primarily poor and rural western provinces in China, little is known about anemia in the more developed provinces of central China. The overall goal of this study is to assess the extent of anemia in central China and determine the effect of anemia on the academic performance of students. Using data collected from fourth grade students in 25 primary schools, we find that 16–27% of sample children are anemic. Female students and students with mothers who have not migrated for work are more likely to be anemic. Importantly, using both regression analysis and matching methods, we find that students with anemia (and those with low hemoglobin levels) are more likely to perform poorly on standardized mathematics exams. These findings suggest that, over the long term, untreated anemia will perpetuate poverty by restricting the human capital development of affected children.

1. Introduction

Iron deficiency anemia is the most common nutritional deficiency worldwide, affecting approximately a quarter of the world's population, primarily in developing countries (de Benoist, McLean, Egli, & Cogswell, 2008; Luo, Wang, et al., 2011). Prolonged iron deficiency impairs hemoglobin production, limiting the amount of oxygen that red blood cells carry to the body and brain. Numerous studies have linked iron deficiency and anemia to cognitive impairment and altered brain functioning (Scrimshaw, 1990; Yip, 2001). Beyond longer term health consequences, childhood anemia is known to impair student academic performance, in terms of measures such as grades, attendance, and years of educational attainment (Bobonis, Miguel, & Puri-Sharma, 2006; Halterman, Kaczorowski, Aligne, Auinger, & Szilagyi, 2001; Stoltzfus, 2001; Stoltzfus et al., 2001). These consequences are irreversible and cannot be remedied even if anemia is corrected in later childhood, leading to reduced human capital accumulation among affected children over the long-term (Haas & Brownlie, 2001; Lozoff & Georgieff, 2006; Lozoff, Jimenez, Hagen, Mollen, & Wolf, 2000; Lozoff, Jimenez, & Smith, 2006; Maluccio et al., 2009).

Despite unprecedented economic growth over the past several decades, the prevalence of anemia remains high in China, particularly in poorer regions. In fact, research has shown that anemia rates among young (pre-school aged) children in China are high enough to be classified as a public health concern by WHO standards (19% of this population – WHO, 2015). In addition, a number of

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studies have since documented a high prevalence of anemia (20%–50%) among fourth and fifth grade students in poor western provinces of China (Luo et al., 2010; Luo, Wang, et al., 2011; Luo, Zhang, et al., 2011; Zhang, Yi, Luo, Liu, & Rozelle, 2013).

Existing studies suggest that anemia is not only a health problem for primary school children in rural China, but is also correlated with poor academic performance. For example, in a study of 40,000 school-age children in Gansu province, the author found that anemia status is significantly correlated with lower levels of academic performance (as measured by decreases in standardized Chinese, mathematics, and science test scores over the study period—Li, 2009). In addition, results from Luo et al. (2012) found that when anemic children were treated with a nutritional supplement, it increased their hemoglobin levels and, in turn, their performance on a standardized math test improved.

While many studies have focused on anemia among students in rural areas of western China, few data have been collected on the prevalence and impacts of anemia in China's central regions. This lack of attention is perhaps because one would not expect a high prevalence of anemia in these areas, given higher average income levels (National Bureau of Statistics, 2011). This expectation would exist because research has shown that there is a link between household socioeconomic status and childhood anemia (Kim et al., 2009). However, it has been found that considerable heterogeneity exists in anemia prevalence even within a single country across different subpopulations (de Benoist et al., 2008). If there are areas of central China where children are considerably more vulnerable to developing anemia than others, the government of China could be neglecting a nutrition-based public health problem affecting millions of children. Even if we consider only a subpopulation of children in central China, the results in this paper are relevant for nearly 200 million children (National Bureau of Statistics, 2015).

In one of the only studies on the topic conducted in central China, researchers report an anemia rate of 9.6% among children aged 7–14 in Henan province in 2009 (Li, Luo, Medina, & Rozelle, 2015). If this rate (9.6%) is high, this would increase the necessity to identify the prevalence of anemia in central China and its effect on educational outcomes. Additionally, if high anemia rates were found to be associated with poorer educational outcomes, it would increase the importance of developing interventions that address anemia, such as free school lunch programs that provide children with micronutrient-rich foods (Luo, Zhang, et al., 2011). Aside from this, no studies in the past decade have documented the anemia rate of primary school children or examined what characteristics are associated with anemia status in rural areas of central China.

While this previous work is important, the current study is designed in a way that has two contributions. First, while the CHNS data do cover rural Central China (in Li et al., 2015), the exact nature of sampling and data collection (especially within the context of collecting and analyzing the blood samples for micronutrient deficiencies) are not fully spelled out. By referring to the CHNS website (http://www.cpc.unc.edu/projects/china), it is clear that the data are certainly not faulty in any way. In fact, the anemia results appear to be coming from a subtest of a full blood draw that was done in the home and that was subsequently send to a lab. Again, while this is fine by itself, perhaps a drawback of this is that such results may or may not be generating results that are consistent with the rest of the literature—which relies on in-school sampling and in-the-field Hemocue Hb 201 + testing. Therefore, these results may not be comparable to those found in other studies on childhood anemia conducted in other areas of China. Additionally, the results of Li et al. (2015) rely on data collected in 2009, prior to the launch of the National Nutritious School Lunch Program (NNSLP) in 2012. This program seeks to address the problem of undernourishment and micronutrient deficiencies among school children, supply nutritious food to poor rural students, and reduce classroom hunger (Ministry of Education, 2012). Taking this into consideration, it is much more meaningful in a policy sense to examine anemia rates post-NNSLP implementation.

The overall goal of this study is to assess the extent of anemia in school-aged children in a rural county of a central Chinese province. To meet this overall goal, we have three specific objectives. First, we describe the prevalence of anemia and average hemoglobin levels among children in our sample. Second, we examine whether certain student characteristics are correlated with anemia status and low hemoglobin levels. Third, we determine how anemia status impacts the educational performance of our sample students.

2. Methods

2.1. Definition of anemia

To achieve our objectives, we first need to establish how anemia is defined and diagnosed. Since 1968, anemia has been diagnosed using hemoglobin level cutoffs set by the WHO for specific age-ranges and gender (WHO, 1968). However, because these cutoffs were established using data from nearly a half-century ago, the appropriateness of these thresholds is questionable.[1] For this reason, we also look to other studies that have examined childhood anemia in China to develop alternative definitions of anemia status (Li et al., 2015; Luo et al., 2010; Luo, Wang, et al., 2011; Luo, Zhang, et al., 2011; Zhang et al., 2013). Ultimately, we use two different hemoglobin level thresholds to define anemia: a) an age-specific cutoff that defines anemia using a hemoglobin level cutoff of 115 g/L for children aged 5–11 years and 120 g/L for children above 12 years (World Health Organization, 1968); and b) a hemoglobin level cutoff of 120 g/L to determine anemia status for children of all ages (Luo et al., 2010; Luo, Wang, et al., 2011; Luo, Zhang, et al.,

[1] There has been considerable debate about the appropriateness of this threshold. Although much of this debate has centered around what hemoglobin values should be considered abnormal and how thresholds should vary by subpopulations, one of the most general arguments is that the definition should be based on observed consequences (functional outcomes) rather than largely arbitrary cutoffs. In a recent paper by Sylvia et al. (2016), it was shown that even at hemoglobin levels above the normal thresholds, raising such levels can lead to improved cognitive outcomes. Because of this, we use the original traditional cutoffs and then also use cutoffs that allow us to measure the share of children that have hemoglobin rates somewhat above the normal cutoffs (since it is highly possible that such children would see learning benefits if their nutrition improved and hemoglobin levels rose).

2011). For most of our analyses, we examine the anemia prevalence among our sample using both cutoffs. In addition, to examine the case of near-anemic sample children who have hemoglobin levels that are just over the established anemia cutoffs and have been shown to stand to benefit from increased hemoglobin levels (Sylvia et al., 2016), we also examine educational outcomes using a hemoglobin level threshold of 130 g/L.

2.2. Sampling

The data in our study come from a survey conducted in one nationally designated poverty county in rural Henan province in 2016. We chose to sample in a county in Henan province given that the average rural income in the province (10,853 yuan per capita) is only slightly lower than that for all of rural China (11,422 yuan per capita) and rural areas of central China (10,919 yuan per capita – National Bureau of Statistics, 2015).

To select our sample, we followed a three-step selection process. First, we obtained a list of all elementary schools in each of the county's 13 townships from the county bureau of education. From this list, we then randomly selected two primary schools from each township, except in one township where there was only one school. In total, then, we selected 25 primary schools. Finally, one fourth grade class was randomly selected in each sample school, and within each class, we randomly selected 20 students for inclusion in the study. In all, we collected data on 493 elementary school students from 25 primary schools.

While the average rate of anemia within the sample schools was 16–27% (given that the average rate differed based on the two different hemoglobin level cutoffs), this does not mean that the rate was the same in all schools. In fact, there was considerable heterogeneity. For example, among our sample of 25 schools, 4 of them had anemia rates in excess of 45%, but there were also 2 schools where the anemia rates were < 5%.

2.3. Data

Data were collected by four enumerator teams, each consisting of two trained nurses and two survey enumerators. The two trained nurses from the Xi'an Jiaotong University School of Medicine measured hemoglobin levels on-site using a Hemocue Hb 201 + finger prick system. The age of each student was obtained from the birth records in each student's matriculation folder, widely considered to be an accurate source.

In each team, two enumerators collected data regarding individual characteristics, household characteristics, and the educational performance of students. The first part of the student survey collected basic socioeconomic and demographic information about each student and their household. The survey questions collected information on each student's age, gender, whether his/her parents graduated from junior high school, the number of children in his/her household, and the migration status of his/her parents.

The second part of the survey collected information on each student's academic achievement based on scores from a standardized mathematics exam. The questions in the exam were chosen by a group teachers from local primary schools based on curriculum standards. The same test was administered at all sample schools in the same week and were proctored by classroom teachers.

2.4. Statistical analysis

To assess the determinants of the anemia status and hemoglobin levels of sample students, we conducted a multivariate linear regression using the following specification:

$$Outcome_{ij} = a_0 + a_1 \bullet Zstudent_{ij} + a_2 \bullet Zparent_{ij} + a_3 \bullet Schooldummy_j + e_{ij} \quad (1)$$

where $Outcome_{ij}$ is either the anemia status (based on age-specific or non-age-specific cutoffs) or hemoglobin level of student *i* in school *j*. $Zstudent_{ij}$ represents individual student characteristics, such as *gender* and *age*; $Zparent_{ij}$ represents parental characteristics, including *father's educational attainment*, *mother's educational attainment*, *father's migration status*, *mother's migration status*, and *number of children in the household*. $Schooldummy_j$ represents the school-level fixed effect for school *j*.

To examine the relationship between anemia status/hemoglobin levels and student academic achievement, we conducted multivariate linear regressions using the following model:

$$Y_{ij} = a_0 + a_1 \bullet Outcome_{ij} \bullet Zstudent_{ij} + a_3 \bullet Zparent_{ij} + a_4 \bullet Schooldummy_j + e_{ij}) \quad (2)$$

where Y_{ij} is the standardized mathematics test score of student *i* in school *j*. Two dependent variables are examined in this model: a child's anemia status or his/her hemoglobin level. $Outcome_{ij}$ is a either dummy variable equal to one if student *i* in school *j* is considered anemic (based on a cutoff of 130 g/L), or is the hemoglobin level of student *i* in school *j*. $Zstudent_{ij}$ represents the vector of observable individual characteristics for student *i* in school *j*, including *gender* and *age*; and $Zparent_{ij}$ represents the vector of observable household characteristics for student *i* in school *j*, including *father's educational attainment, mother's educational attainment, father's migration status, mother's migration status, and number of children in the household*. $Schooldummy_j$ represents the school-level fixed effect for school *j*.

Furthermore, we used propensity score matching (PSM) analysis to identify the impact of anemia on the academic achievement of students. By using PSM analysis, it is possible to reduce the bias in the estimation of treatment effects using observational data sets (Rosenbaum & Rubin, 1983). In our analysis, PSM allows us to match a student in the anemic "treatment group" to a non-anemic student from the "comparison group" with a similar propensity score, and then interpret the difference in their academic performance as the impact of anemia. The propensity score is calculated by estimating a logit model using individual characteristics and household

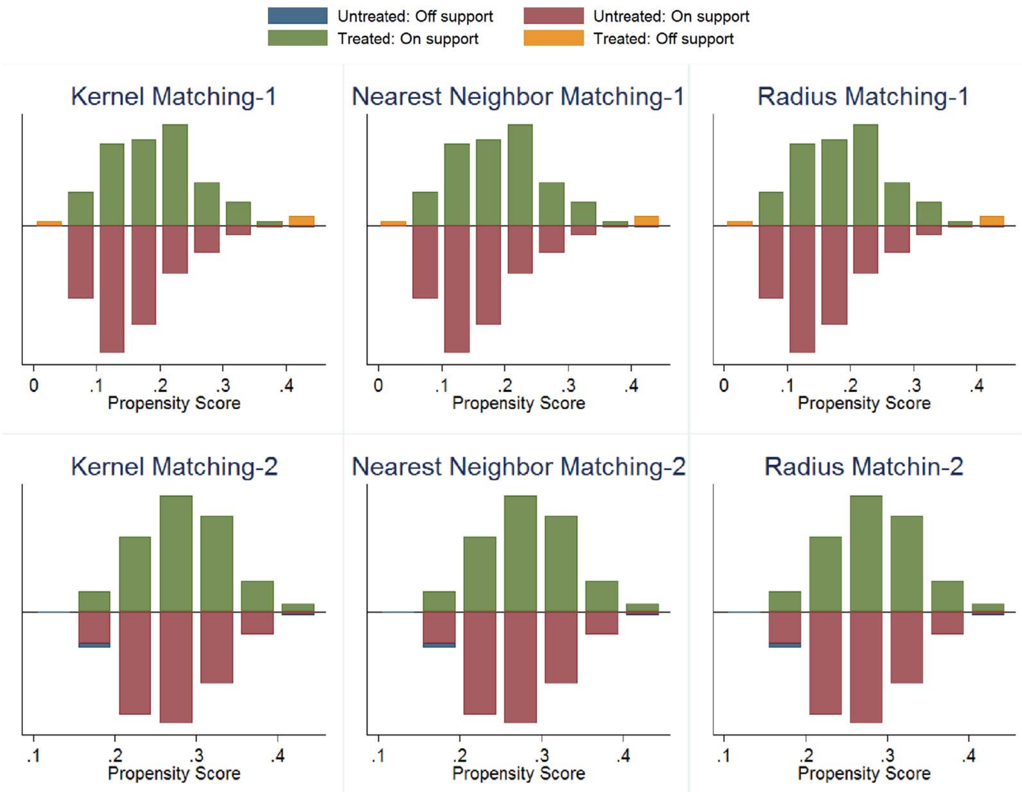

Fig. 1. Overlap in the support of covariates.

characteristics as independent variables. Then, we estimate the average treatment effects on the treated (ATT). ATTs are calculated as a weighted average of the outcome difference between the treatment group and comparison groups (Abadie & Imbens, 2002).

We follow a series of well-established steps to implement the matching estimator successfully (Caliendo & Kopeinig, 2008). First, we check whether there is common support, or a sufficiently large overlap in the propensity scores of the treatment and control groups. We find that the common support is wide in our sample (Fig. 1). Then, we choose the method of matching. In this study, we use three different matching approaches: Kernel Matching, Nearest Neighbor Matching, and Radius Matching. Kernel Matching weights non-treated matches based on their distance from treated observations and can be considered a weighted regression of the counterfactual outcome. Using Kernel Matching, the ATT is calculated as follows:

$$\mathrm{ATT} = \frac{1}{N^T}\sum_{i\in T}\left\{y_i^T - \frac{\sum_{i\in C} y_j^C G(p_j - p_i/h_n)}{\sum_{k\in C} G(p_k - p_i/h_n)}\right\} \tag{3}$$

where y_i^T indicates the standardized mathematics test score of anemic student i in the "treatment" group (T) and y_j^C is the average standardized mathematics test score of all matched non-anemic students j. Every anemic student i is matched with a weighted average of all non-anemic students j with weights that are inversely proportional to the distance between their scores, $p_j - p_i$; $G(\,)$ is a kernel function with h_n as the bandwidth parameter.

Nearest Neighbor Matching is used to ensure that each anemic student is matched to the non-anemic student with the closest propensity score (which is one way to maximize the reduction of selection bias). We conduct our Nearest Neighbor Matching without replacement, meaning that each anemic student is paired one-for-one with a non-anemic student with a similar propensity score. Radius Matching ensures that each anemic student is matched only with the non-anemic student whose propensity score falls into a predefined neighborhood of the propensity score of the anemic student. Both forms of matching can be represented by Eq. (4) below:

$$\mathrm{ATT} = \frac{1}{N^T}\sum_{i\in T} y_i^T - \frac{1}{N^c}\sum_{j\in C} y_j^C \tag{4}$$

where y_i^T indicates the standardized mathematics test scores of anemic student i in the "treatment" group (T) and y_j^C is the "nearest neighbor" non-anemic student j in the comparison student group (C) that is matched to i; N^T and N^C denote the number of anemic students and non-anemic students, respectively.

The last step to implementing matching methods is to assess the matching quality. To do so, we use balance tests to check the distribution of the relevant covariates in both the treatment and comparison groups for each matching method. The treatment and comparison groups are balanced for each form of PSM employed in our study (Fig. 2).

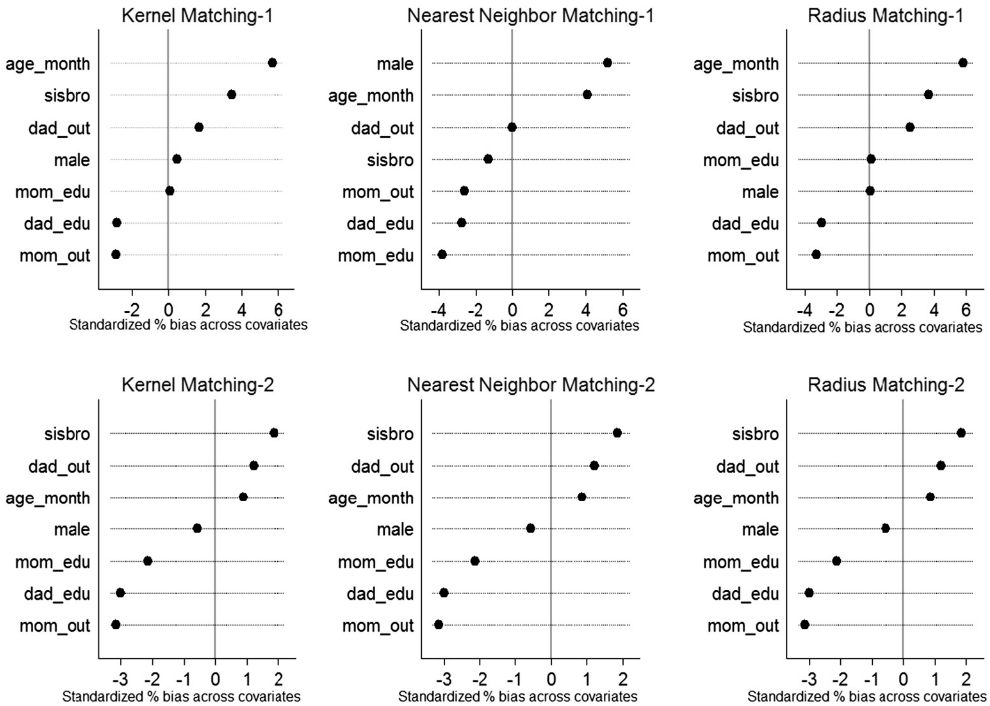

Fig. 2. Standardized percentage bias across covariates after matching.

3. Results

3.1. Prevalence of anemia and the average hemoglobin level in sample county

Our results, which used two different hemoglobin level cutoffs, indicate that anemia is still prevalent among students in rural areas of central China. According to our data, 16% of the sample students were anemic based on our first cutoff measure, the WHO-recommended hemoglobin level cutoff 115 g/L for children aged 5–11 and 120 g/L for children aged 12 and over[2] (Table 1, Column 1, Row 1). When using our second hemoglobin cutoff level, a general anemia cutoff of 120 g/L for all children, 27% of the sample students were determined to be anemic (Column 2, Row 1). We also found that the average hemoglobin level among this sample of children was 125.17 g/L, suggesting that a substantial number of children likely have hemoglobin levels just above our anemia thresholds.

According to WHO, anemia is a serious public health problem when it has a prevalence rate of over 5% in a population (World Health Organization, 2001). We found that the anemia rates between schools varied significantly ($p < 0.001$), ranging between 0% and 50% of students in a given school using the age-specific cutoff established by WHO (World Health Organization, 2001). Of the 25 schools included in our sample, only 5 schools (20% of our sample) had an anemia prevalence rate of < 5%, indicating that anemia is indeed a serious problem in most of our sample schools.[3] While we did not observe any cases of severe anemia (< 80 g/L – WHO, 2011) in our sample (a measure that indicates children are severely malnourished), we still believe that the proportion of primary-school-aged children with anemia in sample schools merits concern. This concern is justified given that research has found that even mild anemia can adversely affect the cognitive abilities of students (Kordas et al., 2004; Sen & Kanani, 2006). If the rates of anemia in our sample schools are at all representative of other areas in central China (and taking into account the prevalence rates that have been found in areas of western China in recent years), this means that > 20 million children in central and western China are sick due to malnutrition.

[2] China's schooling system has clear rules when it comes to the age in which school children should be attending each type school. Specifically, the Ministry of Education required that every child can attend primary school at 6 years old (Ministry of Education, 1986). If all children abided by this rule, then we might not expect to find any 12-year-old children in grade 4. Yet, 7% of the sample of grade 4 students are 12 years old. However, there may be other reason why students are older than Ministry of Education standard. First, despite the rules, it might be that parents could hold their children back and have them start later. Second, the literature also shows that, in China today, there is a high rate of grade of retention. In Chen, Liu, Zhang, Shi, and Rozelle (2010), 35% of the students in rural primary school were found to have repeated at least one grade before they entered grade 6 and the rate was highest for first grade (which is a time before grade 4). If such high rates of retention are common throughout China, then it is clear that there is nothing unusual about the age range of the students in our sample.

[3] Available in supplementary tables at www.reap.fsi.stanford.edu.

Table 1
Prevalence of anemia by individual and household characteristics.
Data source: Authors' survey (2016).

Characteristics	Anemia rate (age-specific hemoglobin level cutoff)[a]	Anemia rate (hemoglobin level < 120 g/L)	Hemoglobin level (mean, g/L)	Percent of sample (n = 493)
Total	0.16	0.27	125.17	100
Gender				
Female	0.20	0.29	124.37	52
Male	0.12	0.26	126.06	48
Age				
Below 10 years old	0.13	0.31	124.62	29
[10–11 years old)	0.13	0.23	125.77	35
[11–12 years old)	0.20	0.28	124.99	30
12 years old or above	0.29	0.29	125.29	7
Education of father				
Below junior high school	0.20	0.31	124.46	29
Junior high school and above	0.15	0.26	125.41	71
Education of mother				
Below junior high school	0.19	0.30	124.31	47
Junior high school and above	0.15	0.25	125.81	53
Migration of father				
No	0.14	0.27	125.57	30
Yes	0.17	0.27	125.00	70
Migration of mother				
No	0.19	0.31	124.69	55
Yes	0.14	0.23	125.77	45
Has siblings				
No	0.14	0.26	125.98	59
Yes	0.2	0.30	124.03	41

[a] Age-specific hemoglobin level cutoff: Calculated based on WHO-recommended hemoglobin level cutoffs of 115 g/L for children aged 5–11 and 120 g/L for children aged 12 and over (WHO, 2001).

3.2. Characteristics associated with anemia and hemoglobin levels

To understand if there are any characteristics that are related to anemia status among our sample of children, we examine how anemia status varies along different individual- and household-level characteristics. In terms of individual-level characteristics, we find that female students were generally more likely to be anemic than male students (Table 1). Specifically, when we use the age-specific hemoglobin level cutoff, the anemia rate among female students is 20%, while the rate for male students is only 12% (Column 1, Rows 2 & 3). In addition, when we use the 120 g/L cutoff, the anemia rate among female students is 29%, but it is only 26% for male students (Column 2, Rows 2 & 3). We also found that the average hemoglobin level of female students (124.37 g/L) was lower than that of male students (126.06 g/L – Column 3, Rows 2 & 3). In other words, not only is the rate of anemia higher for female students than male students, but the distribution for females is also more skewed to the lower end of their hemoglobin distribution. This may suggest that, in addition to having higher rates of anemia, non-anemic female students are also more vulnerable to developing anemia than non-anemic male students. The findings that female students from central China have higher levels of anemia than male students are consistent with the findings of Luo, Wang, et al. (2011) from western China, which found that the anemia rates of female students in western China were 2.9 percentage points higher than those of male students.

When we evaluated differences in anemia prevalence by age using the age-specific thresholds determined by the WHO (1968), we found that anemia rates increased as children aged. Specifically, we found anemia rates of 13% for children under 10-years-old and for 10- to 11-year-old children, and this figure increased to 20% for 11- to 12-year-old children and to 29% for children aged 12 years or over (Column 1, Rows 4–7). However, when we used a general 120 g/L cutoff, we found that, although anemia prevalence increased with age for children aged 10 years or older, the highest anemia prevalence rate was found among children below 10 years of age. Specifically, we found that the anemia rate of children below 10 years of age was 31%, while these rates were 23% for 10- to 11-year-old children, was 28% for 11- to 12-year-old children, and 29% for children aged 12 years and older. Given the results of a recent working paper on the relationship between academic test scores and hemoglobin concentrations (Sylvia et al., 2016), we believe it is important to gauge rates of anemia using multiple age-sensitive cutoffs. The noted research found that younger children are equally likely as or more likely than older children to have hemoglobin levels that may be in ranges where their cognition is affected. For this reason, methods for defining anemia that are more sensitive to the developmental stages of children may more accurately represent the risks anemia places on their human capital development.

In terms of household-level characteristics, we find that when children's mothers or fathers received at least a junior high school education, their anemia rate was lower than that of their peers (Table 1). Specifically, we found anemia rates of 15% and 20% among students whose fathers did and did not complete junior high school, respectively, using the age-specific cutoff (Column 1, Rows 8 & 9). Results were similar when using the 120 g/L cutoff, as we found that students whose father had completed junior high school had an anemia prevalence rate of 26%, which is lower than the rate of 31% found among their peers (Column 2, Rows 8 & 9). For children whose mothers had received at least a junior high school education, only 15% were anemic according to the age-specific hemoglobin level cutoff, which is lower than the 19% prevalence rate for children whose mothers had lower levels of educational attainment (Column 1, Rows 10 & 11). When we used the 120 g/L cutoff, 25% of students whose mother received at least a junior high school education were anemic, while only 30% of their peers were found to be anemic (Column 2, Rows 10 & 11). Although we do not know the underlying mechanisms (as we did not measure dietary intake of children), it is likely that since lower levels of education in China today are associated with lower incomes (Zhang, Huang, & Rozelle, 2002; Zhang & Li, 2003) and lower levels of knowledge about nutrition (Behrman & Deolalikar, 1988; Chen & Li, 2009), that one (or both) of these two forces (being poor and not understanding what constitutes good nutrition) underlies our findings.

Although the education levels of both parents are associated with lower anemia rates, when we used the age-specific hemoglobin level cutoff, we discovered that anemia rates were lower among students whose mothers had migrated for work, and higher among students whose fathers had migrated for work as compared to their peers. Specifically, the anemia rates among students whose father had migrated for work were 17%, as compared to 14% of their peers (Column 1, Rows 12 & 13). Using the same cutoff, we found that the anemia rate among students whose mother had migrated for work was 14%, while the rate was 19% for other students (Column 1, Rows 14 & 15). In addition, using the general 120 g/L cutoff, we found that anemia rates were lower among students whose mothers had migrated for work (23%) as compared to their peers (31%). However, using the 120 g/L cutoff, we found no differences in anemia rates between children whose father had migrated and those whose father had not (both have prevalence rates of 27%—Table 1). In addition, we find that children with siblings had a higher average anemia rate (20%) than children without siblings (14%—Table 1).

The finding that the children left-behind in rural areas by migrating parents have better nutritional outcomes than children that live with their parents in rural areas is not new. In research conducted by Luo, Wang, et al. (2011) and Luo, Zhang, et al. (2011), it was found that children in rural western China that lived with both parents had systematically higher levels of anemia than children who were left at home in rural villages while their parents migrated to cities for work. Although we cannot say with any degree of certainty how maternal migration is related to childhood anemia, one possible explanation is that the increased income earned when a child's mother migrates improves the economic status of the household. Household socioeconomic status is known to be inversely associated with childhood anemia and malnutrition, and may account for the lower levels of anemia in this subgroup (de Brauw & Mu, 2011; Du, Mroza, Zhai, & Popkina, 2004).

3.2.1. *Multivariate analysis of the correlates of anemia*

In addition to using descriptive analysis to examine anemia rates among subgroups of children, we also conducted multivariate analysis to see if any characteristics are significantly related to anemia status, holding other characteristics constant. The results of multivariate analysis showed a significant correlation between anemia status and student gender, but only when using the age-specific cutoffs and not when using the threshold of 120 g/L to determine anemia status for all children. Specifically, using the age-specific cutoffs, we found that female children were 7 percentage points more likely to be anemic than male children, and this finding is significant at the 5% level (Table 2, Column 1, Row 1).

The multivariate analysis also finds that children whose mothers had migrated were significantly less likely to be anemic than their peers when using either the age-specific or general anemia cutoffs. Specifically, when we used the age-specific cutoff, children with mothers who had migrated were 9 percentage points less likely to be anemic than children whose mothers had not migrated, significant at the 5% level (Table 2, Column 1, Row 6). Using the 120 g/L cutoff, we found that children with mothers who have migrated were 11 percentage points less likely to be anemic than their peers, significant at the 5% level (Column 2, Row 6). The results of multivariate analysis showed a significant correlation between mother's migration status and children's hemoglobin levels, on average. Children whose mothers had migrated have an average hemoglobin level 1.87 g/L higher than that of their peers, and this is significant at the 10% level (Column 3, Row 6).

3.3. *The relationship between anemia status and the academic achievement of students*

To investigate whether there is a relationship between anemia status and the academic performance of students, we examined the correlation between hemoglobin level-defined anemia status and academic performance as measured using a standardized mathematics test (see data section above for a description of the exam). Several papers (Luo, Wang, et al., 2011; Luo, Zhang, et al., 2011; Luo et al., 2012; Miller et al., 2012) have reported such a relationship in western China. In fact, in Luo et al. (2012) and Miller et al. (2012), the results were produced as part of a randomized controlled trial, meaning that these papers found a causal relationship between anemia rates and cognitive outcomes.

According to the results in Table 3, anemic students score significantly lower on the standardized math test than their peers. Using the age-specific cutoff, we find that students with anemia performed 0.20 standard deviations worse (significant at the 10% level) than their peers on the standardized math test (Column 1, Row 1). In addition, when we use the 120 g/L cutoff for all students, we find that students with anemia performed 0.19 standard deviations worse than non-anemic students (significant at the 10% level – Column 2, Row 2).

We also find that the hemoglobin levels of anemic and near-anemic students are significantly correlated with higher levels of academic achievement (Table 4). Among a subset of children with hemoglobin levels below 130 g/L, we found that a 1 g/L increase in hemoglobin level was associated with a 0.01 standard deviation increase in standardized math test score (significant at the 10% level). However, it appears that this case holds only for anemic and near-anemic students, as no significant result was found when we conducted the same analysis with the entire sample (results available at www.reap.fsi.stanford.edu).

Table 2
Correlation between individual and household characteristics and anemia status/hemoglobin level.
Data source: Authors' survey (2016).

Dependent variable	Anemia status (age-specific hemoglobin level cutoff)[a]	Anemia status (hemoglobin level < 120 g/L)	Hemoglobin level
	(0 = not anemic, 1 = anemic)	(0 = not anemic, 1 = anemic)	(g/L)
Gender (0 = female, 1 = male)	− 0.07**	− 0.00	0.69
	(0.03)	(0.04)	(0.94)
Age (in months)	0.00	− 0.00	0.05
	(0.00)	(0.00)	(0.05)
Education of fathers (0 = below junior high school; 1 = junior high school and above)	− 0.01	− 0.01	− 0.50
	(0.04)	(0.05)	(1.13)
Education of mothers (0 = below junior high school; 1 = junior high school and above)	0.05	0.01	0.24
	(0.03)	(0.04)	(0.98)
Migration of father (0 = no; 1 = yes)	0.06	0.04	− 1.17
	(0.04)	(0.05)	(1.08)
Migration of mother (0 = no; 1 = yes)	− 0.09**	− 0.11**	1.87*
	(0.04)	(0.04)	(1.00)
Number of siblings	− 0.00	0.01	− 0.64
	(0.02)	(0.02)	(0.54)
School dummy	Yes	Yes	Yes
Constant	− 0.30	0.33	123.69***
	(0.22)	(0.27)	(6.34)
Observations	493	493	493
R-squared	0.17	0.15	0.15

Standard errors in parentheses.
*** $p < 0.01$.
** $p < 0.05$.
* $p < 0.1$.
[a] Age-specific hemoglobin level cutoff: Calculated based on WHO-recommended hemoglobin level cutoffs of 115 g/L for children aged 5–11 and 120 g/L for children aged 12 and over (WHO, 2001).

Table 3
Correlation between anemia status and student academic achievement.
Data source: Authors' survey (2016).

Dependent variable	Standardized mathematics test score (mean = 0, SD = 1)	Standardized mathematics test score (mean = 0, SD = 1)
Anemia status (age-specific hemoglobin level cutoff[a];0 = not anemic, 1 = anemic)	− 0.20*	
	(0.12)	
Anemia status (hemoglobin level < 120 g/L cutoff; 0 = not anemic, 1 = anemic)		− 0.19*
		(0.10)
Gender (0 = female, 1 = male)	0.04	0.06
	(0.09)	(0.09)
Age (in months)	− 0.02***	− 0.02***
	(0.00)	(0.00)
Education of fathers (0 = below junior high school; 1 = junior high school and above)	0.02	0.02
	(0.10)	(0.10)
Education of mothers (0 = below junior high school; 1 = junior high school and above)	0.23**	0.22**
	(0.09)	(0.09)
Migration of father (0 = no; 1 = yes)	− 0.02	− 0.03
	(0.10)	(0.10)
Migration of mother (0 = no; 1 = yes)	− 0.09	− 0.09
	(0.09)	(0.09)
Number of siblings	0.02	0.02
	(0.05)	(0.05)
School dummy	Yes	Yes
Constant	2.14***	2.26***
	(0.58)	(0.58)
Observations	493	493
R-squared	0.24	0.24

Standard errors in parentheses.
*** $p < 0.01$.
** $p < 0.05$.
* $p < 0.1$.
[a] Age-specific hemoglobin level cutoff: Calculated based on WHO-recommended hemoglobin level cutoffs of 115 g/L for children aged 5–11 and 120 g/L for children aged 12 and over (WHO, 2001).

Table 4
Correlation between hemoglobin level and student academic achievement using a sample of anemic and near-anemic students (Hb level < 130 g/L).
Data source: Authors' survey (2016).

Dependent variable	Standardized mathematics test score (mean = 0, SD = 1)
Hemoglobin level	0.01*
	(0.01)
Gender (0 = female, 1 = male)	0.01
	(0.11)
Age (in months)	− 0.02***
	(0.01)
Education of fathers (0 = below junior high school; 1 = junior high school and above)	− 0.09
	(0.13)
Education of mothers (0 = below junior high school; 1 = junior high school and above)	0.19*
	(0.11)
Migration of father (0 = no; 1 = yes)	0.04
	(0.12)
Migration of mother (0 = no; 1 = yes)	− 0.04
	(0.12)
Number of siblings	0.03
	(0.06)
School dummy	Yes
Constant	0.87
	(1.14)
Observations	324
R-squared	0.24

Note: We use a subsample of students whose measured Hb level is < 130 g/L.
Standard errors in parentheses.
**p < 0.05.
*** p < 0.01.
* p < 0.1.

Table 5
PSM results analyzing the effect of anemia status on the academic achievement of students.
Data source: Authors' survey (2016).

	Anemia status (age-specific hemoglobin level cutoff)[a]	Anemia status (hemoglobin level < 120 g/L)
1. Kernel matching	− 0.20 (0.12)	− 0.19* (0.10)
2. Nearest neighbor matching	− 0.15 (0.15)	− 0.20 (0.12)
3. Radius matching	− 0.20* (0.12)	− 0.19* (0.10)

Standard errors in parentheses. *** p < 0.01, ** p < 0.05, * p < 0.1.
[a] Age-specific hemoglobin level cutoff: Calculated based on WHO-recommended hemoglobin level cutoffs of 115 g/L for children aged 5–11 and 120 g/L for children aged 12 and over (WHO, 2001).

3.3.1. Estimating educational impacts using matching methods

The results from our three different types of PSM analysis suggest that anemia may negatively impact educational outcomes (Table 5).[4] Using Kernel Matching, we find that anemia status decreases student academic achievement by 0.19 standard deviations (significant at the 10% level) when we use the hemoglobin cutoff of 120 g/L to determine anemia status for all students (Column 2, Row 1). However, using the same matching approach, we find no significant results when using the age-specific cutoff (Column 1, Row 1). When we employ Radius matching, we find that academic performance decreases by 0.20 and 0.19 standard deviations (both significant at the 10% level) when applying the age-specific and general hemoglobin level cutoffs, respectively (Columns 1 and 2, Row 3). Despite the significant results found using Kernel and Radius matching, both of our results found using Nearest Neighbor matching were insignificant (Row 2).

The results of the OLS and matching analyses examining the relationship/impacts of anemia on education are significant if the conditions found in our sample schools, which are in central China, are representative of the conditions across other regions of central China. In central China, there are currently around 50 million children attending school in grades 1 through 9. If 15–25% of these children are undernourished to the point that they are anemic, this suggests that > 10 million students are prevented from performing to their full potential academically (cognitively) due to malnutrition. In a competitive schooling system, such as the one in China, this means that there would be adverse consequences for anemic students in terms of their academic outcomes, such as test scores, school attendance, and years of educational attainment.

[4] Full regression analyses for all PSM methods are available in supplementary tables at www.reap.fsi.stanford.edu.

4. Conclusion

Our research has found a high prevalence of anemia among rural primary school students in central China. Using the age-specific hemoglobin levels cutoffs defined by WHO, we find that the overall rate of anemia among students in our sample was 16% (WHO, 2001). Also, using a general hemoglobin cutoff of 120 g/L for all students (a measure which we argue is likely important to analyze the relationship between anemia and educational performance), we found that 27% of students in our sample were anemic. Although these rates are high for a normal population of children (World Health Organization, 2001), evidence suggests that this issue goes unnoticed in schools. Indeed, when we proposed doing this study in our Henan sample sites, educational officials discouraged us from doing so saying that they did not believe anemia was a problem in their schools. Such conversations are systematically documented in a study conducted by Luo et al. (2010), which found that over 90% of a sample of principals in rural Chinese schools did not recognize anemia as an issue in their school even though anemia prevalence was high among sample children.

Finding such high rates of anemia among our sample of schools from central China is important because most previous research on anemia prevalence in rural China were conducted in poorer provinces in western China. Although these studies found anemia rates as high as 24.9% and 38.3% (Luo, Zhang, et al., 2011; Luo et al., 2012), our findings still suggest that the prevalence of anemia in rural areas of central China is deeply concerning. Although, compared to schools in western China, central China's schools have moderately lower anemia prevalence rates, more children are likely afflicted with anemia in rural areas of central, rather than western, China. This is because the population in central China, including the population of school-age children, is much higher than in western China (National Bureau of Statistics, 2015). This means, of course, the overall severity of the problem of undernutrition is arguably more serious in central China.

Our analysis also allowed us to identify factors that are correlated with anemia among our sample of students. We found that female students were significantly more likely to be anemic than male students. In addition, students whose mothers migrated for work were significantly less likely to be anemic than their peers. And these relationships held for both the descriptive and multivariate analysis. Results such as these are important since they provide a starting point for designing programs that aim to combat anemia. For example, if resources necessary for a childhood nutrition program are scarce, programs could initially target these more vulnerable groups to reduce childhood malnutrition and its impacts in the most effective manner possible.

In addition to determining anemia prevalence among our sample, we found that anemia is negatively correlated with the academic achievement of students. This finding is consistent with those reached in earlier studies (Li, 2009; Luo, Wang, et al., 2011 ; Luo, Zhang, et al., 2011). Specifically, one study conducted with data on over 40,000 school-age children from Gansu province found that iron deficiency has a negative effect on educational performance (as measured by standardized tests in Chinese, mathematics, and science—Li, 2009). In addition, a study of over 4000 fourth and fifth grade students in rural areas of Qinghai and Ningxia provinces also found that anemia status is correlated with negative educational outcomes (Luo, Wang, et al., 2011; Luo, Zhang, et al., 2011). When we use matching methods to identify the impact of anemia on education outcomes, we find that anemia may significantly deteriorate academic performance. Hence, programs that can effectively reduce anemia are needed not only for improving health outcomes, but also educational outcomes.

The main implication of this work is that childhood anemia remains a serious health concern in rural areas of central China. Given known impact of anemia on the educational performance of students, China's education and health officials should take steps to alleviate the problem not only in the poorer western regions, but also in other areas of China afflicted with high rates of childhood anemia. In the long run, untreated anemia will serve to perpetuate poverty by diminishing the human capital accumulation of rural students, preventing these children from reaching their developmental potential. Implementing measures aimed at improving iron intake would be beneficial in not only the poorest regions of China, but also in comparatively well-off provinces.

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