IMPROVING CHILD HEALTH AND COGNITION: EVIDENCE FROM A SCHOOL-BASED NUTRITION INTERVENTION IN INDIA

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Abstract—We present experimental evidence on the impact of the use of double-fortified salt in school meals on anemia, cognition, and the learning outcomes of primary school children in rural Bihar, one of the poorest regions of India. We find that a year-long intervention had statistically significant positive impacts on hemoglobin levels and reduced anemia by 20%; however, these health gains did not translate into significant impacts on cognitive performance, test scores, and school attendance. Treatment effects on anemia and test scores were larger for children with higher school attendance. The findings indicate that school-based health interventions are a cost-effective and scalable approach for reducing anemia among school children in resource-constrained countries.

I. Introduction

GLOBALLY, around 42% of children under the age of 5 suffer from iron deficiency and are classified as anemic. The prevalence of anemia is highest across South Asia and sub-Saharan Africa, where more than 50% of the children are anemic (WHO, 2016). Two-thirds of Indian children under the age of 5 are anemic, one of the highest prevalence in South Asia (IIPS & ICF, 2017), and a significant proportion of daily deaths in this age group is caused by iron deficiency. Redressing this problem is vital for human capital formation in developing countries, as anemic children are less healthy, have lower cognitive abilities, attain lower educational levels, and are less productive in labor markets (Maluccio et al., 2009; Currie & Vogl, 2013; Chong et al., 2016). Previous research has shown that better childhood health has sizable economic returns and has improved standards of living worldwide (Bloom, Canning, & Jamison, 2004; Baird, Miguel, & Kremer, 2016).

While it is well documented in the efficacy studies that salt fortified with iron and iodine, known as double-fortified salt (DFS), can address iron deficiency among anemic individuals, there remains a critical gap between the efficacy (potential effect) and the effectiveness (actual effect under real-world conditions) of DFS, particularly in settings beset by inefficient program delivery and low adoption of health programs and products (Ramirez-Luzuriaga et al., 2018). The effective scale-up of the DFS intervention depends on supply-side (a delivery mechanism) as well as demand-side factors (program compliance). These two obstacles have kept the benefits of DFS from reaching their full potential. Thus, an important policy decision in anemia prevention is the choice of distribution channels, which are simple, scalable, cost-effective, and have a wide geographic and socioeconomic reach to ensure high and consistent compliance. The evidence on such a delivery mechanism for micronutrient supplementation program is scarce. Banerjee, Barnhardt, and Duflo (2018) found that market-based or free delivery of DFS had low take-up and limited impacts on anemia, while other studies showed that schools can be an efficient channel for the delivery of health programs as they avoid take-up decisions at the household level and can ensure better program compliance (Miguel & Kremer, 2004; Bobonis, Miguel, & Puri-Sharma, 2006). Schools can be attractive and promising platforms for delivering DFS because they provide a readily available and extensive infrastructure that can reach at-risk children at a low marginal cost.

However, two factors may limit the success of school-based nutrition interventions: low attendance and leakages in the program delivery system. Regarding attendance, the evidence from developing countries shows that public schools in rural areas do not suffer from low attendance, as school meal programs have improved attendance in South Asia (Afridi, 2011) and sub-Saharan Africa (Alderman, Gilligan, & Lehrer, 2012; Kazianga, De Walque, & Alderman, 2012).

Regarding issues related to program implementation, leakages in the supply chain and corruption may limit the impacts of school-based programs. These factors are likely to affect compliance by the school and treatment exposure in children. For instance, in developing countries, where schools are resource-constrained, new health programs may crowd out resources from existing programs, and potentially reduce instructional quality (Berry et al., 2019). Therefore, the net welfare gain of school-based delivery of health programs is less clear in developing countries where public schools and service delivery are often not of high quality. Remarkably little is known about the effectiveness of the DFS program at scale, and it remains an empirically open and policy-relevant question to examine whether a school-based DFS program can be effective in reducing anemia among school children in settings with weak state capacity to deliver health programs and poor quality of public schools.

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To shed light on these questions, we set up a large-scale randomized control trial in a rural district in the Indian state of Bihar, a state that has a high anemia prevalence among children. We examine the impacts of a school-based nutrition intervention that provided DFS for school lunch preparation on anemia, cognition, and learning outcomes among primary school-age children. Our study takes advantage of the world's largest school feeding program, the midday meal (MDM) in public primary schools, as a delivery channel for iron supplementation through the distribution of DFS. The Indian MDM program covers more than 100 million children in about 1.2 million schools and provides free meals to all children who attend a public school from grades 1 to 8.

Specifically, we conducted our experiment in two administrative blocks of the Jehanabad district in the state of Bihar, India. Bihar is a relevant setting to examine these questions—the state has limited capacity to deliver health services and continues to rank at the bottom of all indicators of human development. Although the anemia rate among children in Bihar (58%) is one of the highest in the country, the high rate of primary school enrollment (94%) and widespread provision of MDM in 70,000 schools, covering 10 million children every day, provides a unique setting to evaluate the impacts of the DFS intervention on children's health and learning outcomes.

Our intervention supplied subsidized DFS for MDM preparation for one year to 54 randomly allocated treatment schools. Fifty-three control schools continued to use non-DFS salt (mostly iodized salt). Our analytical sample includes 2,000 grade 2 children selected from 107 public primary schools in rural Bihar. Using the difference-in-differences (DD) method with child fixed effects, we find that the year-long DFS intervention had significant improvements in health outcomes but limited impacts on cognition and test scores. The treatment increased the mean hemoglobin (Hb) level by 0.19 g/dL and reduced any form of anemia and mild anemia by 22% and 27%, respectively. The impacts on cognitive performance, test scores, and school attendance, however, were close to 0. Heterogeneity analyses find larger treatment effects for students who had a higher attendance rate. We find evidence of gendered impacts of the intervention as well; the effects were larger and significant for girls compared with boys, and, finally, the treatment effects did not differ by the baseline anemic status of children.

The key challenge in the successful scale-up of DFS intervention is ensuring high take-up and product compliance. Even a well-implemented program can fail when households have to make a choice (Banerjee et al., 2018). In experimental studies, take-up of health programs or products can be increased by active encouragement design, as well as program supervision and monitoring (Thomas et al., 2006; Chong et al., 2016); however, these approaches are resource-intensive and logistically burdensome in real-world situations. Therefore, in settings where supervision and monitoring of health programs are not feasible in the broader community, school lunch programs could be effective in increasing the adoption of health programs and products. Thus, DFS intervention through the school lunch program could potentially be a low-cost, less burdensome, and effective strategy to ensure higher compliance among a sizable proportion of school-age children in rural areas, as most of the rural children attend public schools. The percentage of primary school-age children attending government schools in rural Bihar is close to 90% (NSS, 2014–2015). Elsewhere, several small-scale randomized trials have used school meals to deliver micronutrients to children: van Stuijvenberg (2005) in South Africa, Zimmermann et al. (2003) in Morocco, and Radhika et al. (2011) in India. All of these studies found school feeding programs to be effective in distributing micronutrients to school children. However, evidence on the effectiveness of these studies when scaled-up is limited.

Our paper adds to the literature on the effects of nutritional intervention on children's health and cognitive outcomes and the effectiveness of school-based health interventions in several important ways. First, it adds to the evidence on the effectiveness of DFS on health outcomes such as hemoglobin levels and incidence of anemia. Although previous efficacy trials have demonstrated positive impacts of DFS consumption on anemia (Ramirez-Luzuriaga et al., 2018), evidence for its effectiveness when scaled-up in real-world conditions is limited. To the best of our knowledge, ours is one of the handful of studies conducted at scale to use DFS in a school feeding program to address iron deficiency among primary school-age children in India. Our findings shed light on the use of a school lunch program in ensuring higher compliance for fortified products and reducing nutritional deficiencies among children.

Second, our findings contribute to the debate on designing policies to deliver micronutrients to school children in developing countries. Our findings show that in contrast to market or free delivery of DFS to households, school-based meal programs can be an effective channel for iron delivery and thus for anemia reduction among school children. Third, our findings also contribute to the limited literature on the crowding out of existing school activities when new programs are introduced. Berry et al. (2019) find that the introduction of a micronutrient intervention program in India hampered the implementation of existing programs in the school. Although we do not test this assertion in this study, we believe that the simple and scalable DFS intervention in our study is less likely to crowd out resources for existing programs at schools because the marginal cost of implementing the DFS intervention is extremely low. The school meal-based DFS intervention does not require skilled knowledge or adherence to specific protocols and, therefore, does not add constraints to existing school resources. Finally, we assess DFS impacts not only on health but also on cognitive performance and test scores—important for long-run human capital accumulation and of interest to social scientists and policymakers in resource-poor countries.

II. Background and Related Literature

A. Related Literature

Three strategies are commonly used to combat iron deficiency: iron supplementation, dietary diversification, and food fortification. Iron supplements are effective (Thomas et al., 2006; Chong et al., 2016), but they are expensive and not easily affordable for low-income populations. Iron supplementation also suffers from poor compliance because it is an active intervention that depends on the individual's ability to remember to take the supplements daily (Diosady, Mannar, & Krishnaswamy, 2019). Dietary diversification is also expensive, depends on the local availability of food, and in many settings, it is culturally and religiously inappropriate (e.g., animal sources). In contrast, food fortification is an inexpensive and effective intervention to reduce iron deficiency among low-income households. However, food fortification has some limitations because in many parts of the world, especially in rural areas, fortified food products such as cereals, rice, and wheat are not readily available. In those settings, double-fortified salt could be a cost-effective and sustainable product to reduce iron deficiency because it is readily available, relatively inexpensive compared with other iron-fortified products, and consumed daily regardless of the household's income (see online appendix I for a more detailed discussion of the related literature).

B. India's School Lunch Program

The Indian MDM program is the world's largest supplementary school lunch program and covers all primary (grades 1–8) schools. The MDM scheme was launched nationwide in 1995 to increase primary school enrollment and school attendance, and simultaneously reduce classroom hunger and nutritional deficiencies among primary school children in Indian public schools. Before 1995, two states, Tamil Nadu and Gujarat, were already providing school lunches in primary schools. However, the 1995 directive to implement the MDM scheme in all public primary schools was not followed by many states until a Supreme Court order in 2001. In response to severe drought in several states in 2001, India's Supreme Court directed all state governments to implement the MDM scheme and provide free school lunches to every child in all public primary schools. The lunch should contain a minimum content of 300 calories and 8 to 12 grams of protein each day for at least 200 days a year.

In terms of its scale and coverage, the MDM is one of the largest school feeding programs in the world, covering an estimated 104.5 million children in 1.16 million schools in 2013–2014 in India (Ministry of Human Resource Development, 2016). Several evaluations of the MDM scheme found positive effects on school attendance (Afridi, 2011), primary school enrollment (Jayaraman & Simroth, 2015), learning achievements (Chakraborty & Jayaraman, 2019), and health gains for drought-exposed children (Singh, Park, & Dercon, 2014). In Bihar, about 10 million students in grades 1 to 8 in 70,000 schools eat a midday meal every day (MOHRD, 2016). Each child is supposed to receive a daily lunch meal that is predefined in terms of calories and composition of food items. The menu is fixed by the state government for all schools and varies daily but is repeated every week. In most Indian regions, including the state of Bihar, the MDM is prepared in the school kitchen. The Food Corporation of India provides grains directly to the schools, and usually the headmaster buys the remaining ingredients (e.g., vegetables, pulses, oils, and spices) at the local market. In 2019, the average cost of cooking a meal was approximately US¢6.4 for lower primary school children (grades 1–5) and US¢9.6 for upper primary school children (grades 6–8). This amounts to an annual cost of \$13 for lower primary and \$19 for the upper primary school children for the mandated 200-day school year (Exchange rate: INR 1 = US\$ 0.014 in 2019).

We consider the midday meal program as the distribution channel because the use of fortified products in a school lunch program is not an individual decision but a governmental one. Therefore, if implemented well, it has the potential for high compliance, as using DFS in the MDM is comparable to a (partly) mandatory fortification policy. Furthermore, the use of DFS in the MDM enables a regular, steady, and daily provision of iron to children, which is better than the intermittent provision of iron supplementation. Since the public school infrastructure is well established even in rural areas (nearly every panchayat in India has a primary school) and many children from low-income households attend public schools, school feeding programs can reach a larger fraction of the high risk children at low marginal cost. Therefore, we believe that the midday meal program can be a cost-effective distribution channel because the existing logistical infrastructure is already in place. Additionally, since the treatment in our study is a substitution of conventional iodized salt by DFS, it is unlikely to crowd out other school activities (instructional time), a concern raised in other time- and resource-intensive supplementation programs.

III. Intervention and Study Design

A. Program Implementation and Distribution of Double-Fortified Salt

For the potential scale-up of the program, it is critical to understand the implementation and delivery mechanism of our DFS program. Our intervention was inexpensive, simple, and less resource-intensive than other iron supplementation programs that suffer from leakages, interruption, and crowding out of limited school resources. We partnered with a large private firm (Tata Chemical Limited) to purchase the DFS, Tata Salt Plus, every month. Our project team placed the monthly order on the phone, and the firm's representative delivered the salt to the district headquarter. Thereafter, the salt was either delivered to the school headmaster by our field staff or if the headmaster was purchasing other MDM ingredients in town, he would collect it himself from the project warehouse.

The intervention provided DFS to schools at a discounted price of INR 12 (US$ 0.18), which is equivalent to the price of non-DFS salt sold locally. Since schools were already paying INR 12 for the non-DFS salt, our intervention did not impose any additional financial burden on the treated schools. The cooks in the treated schools were instructed to use DFS in the MDM preparation. Storage requirements for DFS were the same as for iodized salt. The intervention also did not require any special training for the cooks, as mixing salt in the food is not very technical and there is no fixed procedure to follow on how to mix salt with food. Cooks were advised to use DFS the same way they were using salt in the past. Training was not required because of the minimal possibility of overuse or overdose, as salt is used based on taste, and individuals do not prefer food that is too salty; therefore, it is unlikely that cooks would use too much salt to accelerate the effect on health outcomes. In summary, our simple and low-cost intervention entailed only the replacement of previously used salt with DFS, and we did not make any change to the implementation of the MDM scheme.

Our delivery network worked well in ensuring the smooth delivery of salt to treated schools: more than 98% of headmasters and cooks reported not experiencing any major difficulties with the delivery and use of the DFS. Headmasters were instructed to contact the study team if they ran out of DFS before the next planned delivery date. Our study also received the support of district-level education and health officials who instructed the headmasters to comply with the use of DFS in the school lunch preparation. Furthermore, our field staff made one unannounced visit to treated schools each month to monitor the availability and use of DFS, meal quality, and delivery of MDM to students. The monthly school visits thus functioned as a credible monitoring system. Neither the students nor their family members were informed about the treatment, and only the headmasters and cooks were aware of the intervention. Our simple delivery mechanism ensured timely delivery of salt to schools, and the support of the government officials ensured the use of salt in the MDM.

The DFS formula was developed by the National Institute of Nutrition (NIN) Hyderabad and is produced by a few private manufacturers. The DFS used in our study is fortified with 0.86 mg of iron per gram of iodized salt and is generally formulated to provide up to 50% of the daily dietary iron requirement.[1] The form of iron added to the DFS was ferrous sulfate ($FeSO_4$), which in general has higher bioavailability compared with other forms of iron. The daily iron requirement for children 7 to 9 years of age is 10 mg and 8 mg for children 4 to 6 years old. By matching the daily amount of salt used for MDM cooking at schools with the rate of child attendance, we calculate that on average, 4 g of DFS or 3.5 mg of iron (4×0.86) per meal was served to children in our study. This implies that our intervention was intended to provide approximately 35% of the daily iron requirement. At an average school attendance rate of 80%, we estimate that students received 17.5 mg of iron per week from our DFS intervention; however, the actual iron intake depends on compliance and school attendance. Laboratory studies show good stability of the iron and iodine content of the NIN formula of DFS.

B. *Study Location, Sample, and Randomization*

The study was conducted in two administrative blocks (Kako and Modanganj) in the Jehanabad district in the state of Bihar. The administrative blocks were selected due to their geographic proximity to Jehanabad town (the district headquarter) and administrative, logistical, and financial constraints. We randomly drew a representative sample of 108 government primary schools from the sample universe of 228 schools in the two selected blocks and then randomly assigned schools to treatment and control groups. To increase statistical power and minimize variance, we selected a balanced sample of 54 treated and 54 control schools. A computer-generated list of random numbers was used for the allocation of the treatment and control groups. However, by the time an endline survey was administered, one control school was inaccessible due to monsoonal flooding and therefore had to be excluded from the study. The final sample thus had 54 treated and 53 control schools.

The treatment schools received the DFS for MDM preparation while the control group continued to use conventional iodized salt. DFS otherwise was unavailable and mostly unknown throughout the study region, primarily due to supply-side bottlenecks and slightly higher cost. DFS costs 70% more than the conventional iodized salt sold in the local market. This reduced the chance of treatment spillover to the control schools. On average, 20 children from the second grade were randomly selected from each of the sampled schools for the survey which resulted in a baseline sample size of 2,005 children.

The study sample, in general, is representative of and comparable to the population in the state. Among children 6 to 59 months old, 63.5% were anemic in Bihar compared to the national average of 59%, and 61.4% were anemic in Jehanabad district (IIPS & ICF, 2017). Regarding learning outcomes, 38.9% of the children in grades 3 to 5 could read grade 2–level text in Jehanabad district compared to the state average of 31.9% in 2016 (ASER, 2016). The average student per teacher ratio in our sample is 38:1 which is identical to the district average (DISE, 2015–2016); the percentage of schools with fewer than 50 enrolled students is 6.2% in the district and 5% in our sample; the district average for MDM provision is 99% of schools and 100% in our study sample; the average number of teachers per school in the district was 6.5, and the sample average was 6.2 teachers.

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[1] We sent a sample of the DFS for lab testing in Kolkata to verify the level of iron fortification. The lab results were consistent with the fortification level printed on the DFS salt package.

Second graders were chosen because of the strong biological basis for the post-infancy effects of iron deficiency on the neurobiological development of the brain. Specifically, the frontal lobes continue to develop until adolescence and experience spurts of development between the ages of 7 and 9 as well as in the mid-teens (Thatcher, 1991; Anderson, 2002). Children in the second grade are about 6 to 7 years old and hence are in the most critical post-infancy periods of brain development. Among other functions, the frontal lobes are known to mediate advanced interrelated cognitive skills. These include the so-called executive functions, such as response inhibition, task switching, planning and organizing, working memory, abstraction, initiation, and self-monitoring (Anderson, 2001; Salimpoor & Desrocher, 2006)

IV. Data

The baseline survey was implemented between November 2014 and January 2015. The DFS treatment started in August 2015. Implementation of the treatment was delayed because of the earthquake in Nepal in 2015 that also affected Bihar and led to delays in the reopening of schools after the holidays. It was further delayed because of a teacher contract strike, which led to many schools ceasing operations for several months. An endline survey with the same children was administered from August to October 2016, approximately twelve months after the treatment. The endline survey was similar to the baseline survey and, in general, focused on household demographics, socioeconomic characteristics, children's health and cognitive ability, educational outcomes, diet quality, access to health care, and school characteristics. Cognitive tests were conducted at school, and anemia testing was done at home with parental consent. Children who were absent in school on the testing day were tracked and given the cognition tests at home. The refusal rate for the hemoglobin test was less than 1%.

A. *Description of Outcome Variables*

The primary outcome of interest is the hemoglobin level and anemia status of children. We define any anemia as an Hb value <11.5 g/dl, mild anemia as an Hb value ≥ 11 and <11.5 g/dl, moderate anemia as an Hb value ≥ 8 and <11 g/dl, and severe anemia as an Hb value <8 g/dl (WHO, 2011). We observed only a few cases of severe anemia at baseline and endline and thus collapsed moderate and severe anemia into one category.

The secondary and downstream outcomes are cognition ability, test scores, and school attendance. A diverse set of tests was used to assess the different domains of cognitive performance. Cognitive ability was measured by five cognitive tests: forward digit-span, backward digit-span, block design, Stroop-like day-and-night test, and Raven's colored progressive matrices (Hale, Hoeppner, & Fiorello, 2002). Most of the cognitive tests assess higher executive functions, which are supposed to develop at the age of our sampled children (see table A1 in the appendix for a detailed description of the cognitive tests).

We also collected data on the math and reading skills of the children. The math and reading tests were adapted from the Annual Status of Education Report (ASER, 2016) test material developed by the Indian nongovernmental organization PRATHAM. Reading scores ranged from 0 to 4 and math scores from 0 to 15. All three test scores (cognition, math, reading) were normalized.[2] We collected school attendance from the school's official attendance record. The school attendance for each child was calculated by the total number of days that the child was present, divided by the total number of days school was open in the twelve months before the survey.

The control variables included in the estimation are household size, mother's and father's years of schooling, asset index, and school characteristics to adjust for school quality (total enrollment, class size, and student-teacher ratio). The asset index was generated using the first component of a principal component analysis (PCA) consisting of several household assets (see appendix II). Although we randomly sampled 2,005 children at the baseline, complete information was collected only for 1,791 children. Due to attrition (discussed later), the estimation panel has 1,406 ($T = 726$ and $C = 680$) and 1,395 ($T = 717$ and $C = 678$) children for anemia and education sample, respectively. To take advantage of the panel nature of the data, our main analysis uses the balanced panel of children who were surveyed in the baseline as well as in the endline.

B. *Balance Checks at Baseline*

Appendix tables A2 and A3 show the balance tests for the baseline characteristics for the anemia and cognitive sample, respectively. Columns 5 to 8 show the base-year characteristics for the full sample (without attrition), as well as the *p*-values for the difference in means between treatment and control groups. Columns 1 to 4 show the balance check for the estimation sample (with attrition).

Tables A2 and A3 reveal that random assignment to the treatment group produced a control group that is balanced on most of the baseline characteristics in the sample with and without attrition. There are no statistically significant differences between the two groups except for health outcomes. All the control variables in panels B and C are balanced across treatment and control at baseline. However, in panel A of tables A2 and A3, Hb levels are not balanced, and the difference across the treatment arms is statistically significant. The imbalance in Hb level resulted in an imbalance in the other two health outcomes: any anemia and mild anemia. Since randomization was carefully monitored and correctly done, we attribute the base-year imbalance in the outcome

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[2] We normalize the test scores by subtracting the baseline mean of the control group and dividing by the baseline standard deviation of the control group of the given test for both baseline and endline data.

variables to chance. In the anemia sample, the baseline Hb level was slightly higher in the control group and the prevalence of anemia lower, indicating that treated children had worse health outcomes than control children. Children assigned to treatment schools have 9 percentage points (pp) higher prevalence of anemia than the control group, potentially biasing the program effects in the downward direction (bias against finding significant program effects). Since our regression model includes child fixed effects, this difference in the baseline outcome variables is always accounted for in the estimation. Overall, these results indicate that the randomization was successful except for the health outcomes, and treatment status is likely to be orthogonal to observed and unobserved characteristics of the sample.

C. *Sample Characteristics*

The baseline characteristics in table A2 reveal a picture of severe poverty characterized by high morbidity levels, low education, low socioeconomic status, low diet quality, and poor access to health care. The average incidence of anemia is 42%. The average years of schooling for fathers and mothers are 5.5 and 1.7 years, respectively. The family size is large (about 7.9 persons), and the hospital-based delivery rate is 40%. Furthermore, very few households have access to improved sanitation (7%), but despite this low level of sanitation access, the prevalence of diarrhea is extremely low (4%). One-fourth of the children belong to a socially disadvantaged caste (scheduled caste and tribe), and 54% of the children are female. The average enrollment in the schools is 222 students, and the mean number of students per teacher is 36. The average class size is 28 students in the sample schools.

D. *Sample Attrition*

The attrition rate in our sample is about 20% on average. However, the difference in the attrition rate across the experimental arms is not very high (2.2%) and is statistically insignificant (p-value = 0.25). We examine the correlates of attrition in table 1 to understand the nature of selection into the follow-up survey. Table 1 reports the results from the regression of the attrition indicator on treatment, observed baseline characteristics (gender, anemic status, and Hb level of the child; whether mother has completed primary schooling; family size above mean; religion; asset tercile; school enrollment; class size; and student-teacher ratio), and interaction between the treatment and the observed characteristics. Column 1 shows the results for the anemia sample, and columns 2 and 3 report the results for the cognition and education samples, respectively. None of these baseline characteristics predict attrition, and there is no evidence of differential attrition between treatment and control groups by these characteristics. Neither baseline Hb level nor anemic status affects attrition probability. The p-value for the joint F-statistics on the interactions suggests that they are jointly insignificant (the p-value ranges from 0.28 to 0.74 across columns). These results show a lack of differential attrition, as attrition rates are not statistically significantly different across the treatment and the control groups.

Table 1.—Correlation between Attrition and Pretreatment Characteristics
Prob (attrition = 1)

	Anemia sample (1)	Cognition sample (2)	Attendance sample (3)
Treated	0.124	−0.386	−0.111
	(0.357)	(0.336)	(0.318)
Baseline anemic (Hb < 11.5)	0.036	−0.008	0.012
	(0.057)	(0.054)	(0.045)
Baseline Hb levels	−0.011	−0.018	−0.017
	(0.022)	(0.020)	(0.020)
Female	−0.036	-0.054^{**}	−0.006
	(0.027)	(0.027)	(0.024)
Mother is primary schooled	0.052	0.009	−0.053
	(0.038)	(0.044)	(0.035)
Hindu religion	−0.019	−0.031	0.017
	(0.085)	(0.078)	(0.105)
Above median family size	−0.010	0.034	0.020
	(0.026)	(0.028)	(0.025)
Treat × Baseline anemic	−0.103	−0.001	−0.055
	(0.069)	(0.065)	(0.058)
Treat × Baseline Hb levels	−0.012	0.028	0.013
	(0.029)	(0.027)	(0.025)
Treat × Female	0.003	0.045	−0.000
	(0.039)	(0.040)	(0.039)
Treat × Mother is primary schooled	0.042	0.039	0.053
	(0.060)	(0.058)	(0.047)
Treat × Hindu	0.013	0.022	−0.042
	(0.104)	(0.100)	(0.120)
Treat × Family size	0.019	−0.015	−0.022
	(0.037)	(0.039)	(0.034)
Observations	1,789	1,727	1,667
p-value from joint F-statistics on the interactions	0.42	0.74	0.28

Robust standard errors clustered at school levels are in parentheses. Coefficients reported are from a linear probability model. All models control for asset tercile, total enrollment, class size, student-teacher ratio, and block fixed effects. Coefficients for these control variables are not shown in the table, but none of them are significant, and they are available on request. Baseline anemic is a dummy variable and coded as 1 for children with less than 11.5 Hb levels. Significant at **5%.

We also do not find any significant evidence of selective attrition, as the means of observable characteristics are the same across treatment and control groups (columns 2 to 4 in tables A2 and A3). Table A4 checks selective attrition among attritors, and there are no systematic differences between the treatment and the control groups even among the group of attritors. Although our study suffers from neither differential nor selective attrition, we still use the inverse-probability-of-attrition weighting method as a robustness check.

V. Empirical Framework

A. *Effect of the DFS Intervention Program*

To estimate the effect of the DFS intervention on anemia and cognition, we combine the randomized design with a DD regression approach. By comparing the difference in average outcome in the treatment and control groups before and after the DFS intervention, the DD estimator enables us to control for any remaining observable and unobservable preintervention differences between groups that could confound our results. The DD specification takes the following form,

$$Y_{ist} = \alpha_i + \beta_1 Post_t + \beta_2 Post_t \times Treat_s + \delta_1 S_{st} + \delta_2 X_{it} + \epsilon_{ist}, \quad (1)$$

where Y_{ist} is a vector of outcomes for child i at school s at time t; α_i is the child-specific intercept; $Post_t$ is a binary variable that takes the value of 1 for the post-treatment period and hence captures the secular time trend; $Treat_s$ is a binary variable for assignment to the treatment school; S_{st} is a vector of time-variant school control variables; X_{it} is a vector of time-variant household control variables; and ϵ_{ist} is the error term. We include these control variables to account for any slight imbalances that the data may have and to increase the precision of our treatment effect estimates. We include school-level controls to adjust for the direct role of school characteristics on the program impacts through either better implementation of the MDM scheme or better adherence to the treatment. Household control variables include family size, mother's and father's education levels, and asset index, and school control variables include total student enrollment and student-teacher ratio. In all specifications, we cluster the standard errors at the school level, the level of randomization.

The DD identification strategy relies on the assumption that there should be no omitted factors that affect both the outcome and the treatment status. Since this is a randomized experiment, this assumption is satisfied. The main parameter of interest is β_2, which estimates the causal effect of DFS on anemia, cognition, and learning outcomes. Our estimated effects are intention-to-treat (ITT) because children's outcomes are analyzed based on their treatment status regardless of their actual participation in the program. The ITT provides more conservative estimates as it captures the effect of treatment status regardless of actual take-up of the treatment and thereby reduces the risk of bias caused by differential attrition. Since the treatment variable is constant within the child, the main effect of treatment ($Treat_s$) is absorbed by the child fixed effects, which is why it is omitted in equation (1).

VI. Results

A. *Program Compliance and Take-Up of DFS*

Before discussing the main findings, it is crucial to establish the first stage: availability and use of DFS in the treated schools and differences in iron levels in MDM across treated and control schools. The institutional and program implementation details discussed above, combined with the procurement and distribution data, indicate that our experiment was successful in ensuring high program take-up among the treatment schools. Program compliance is measured through the headmaster and cook survey, administered at the endline, in which headmasters were asked questions about the delivery and use of DFS in the school lunch. There may be concerns that leakages or faulty program implementation may have interrupted and diluted program compliance and take-up. However, the monthly distribution of DFS during the intervention period (August 2015–July 2016) shows salt was delivered to the treatment schools regularly (figure A1). On average, treatment schools received 500 kg of salt per month, amounting to 9 kg of salt per school per month. The monthly distribution of DFS ranged from 392 kg to 792 kg during the intervention period. No salt was supplied in June 2016 due to school closure for summer vacation. We analyze three measures of program take-up: whether the survey team found DFS in the school kitchen during the unannounced visits, who delivered the salt to the school, and whether food color changed in the past twelve months.

During unannounced visits to the school, our field staff always visually inspected the availability of the DFS packet in the kitchen and also checked the color of the food. If DFS was used in the MDM preparation, the food would become slightly brown/black. In the treatment schools, either our field staff delivered the salt or the headmaster collected it from the warehouse, but salt was always procured from local shops in the control schools. To estimate the take-up of DFS, we estimate the following DD model,

$$Y_{st} = \alpha_s + \alpha_2 Post_t + \alpha_3 Post_t \times Treat_s + \epsilon_{st}, \quad (2)$$

where Y_{st} is a binary variable and equals 1 if DFS was present in the kitchen during the unannounced visit and 0 otherwise; $Post_t$, and $Treat_s$ are the same as in equation (1). This analysis is conducted at the school level and includes school fixed effects. Standard errors are clustered at the school level. The parameter of interest α_3 gives us the DD estimate of DFS intervention on the availability of DFS in the school kitchen. We further utilize the endline data on the source of salt delivery in schools and the quality of food to obtain suggestive evidence on program compliance. We estimate the following simple difference (SD) model,

$$Y_s = \alpha_4 + \alpha_5 Treat_s + \alpha_6 S_s + \mu_b + \epsilon_s, \quad (3)$$

where Y_s is a binary indicator of salt delivery by our project team or of food color change at the endline as noticed by the headmaster. Since the model cannot include school fixed effects in equation (3), we include fixed effects for administrative blocks (μ_b) and school-level controls (S_s) to account for the time-invariant characteristics of block and school, respectively.

Table 2 estimates show significant differences across the treatment groups in the availability of DFS in the kitchen, source of salt delivery, and change in food color. The DD model in column 1 shows that the treatment schools had a 92.6 pp higher probability of having DFS in the kitchen compared with the control schools. Regarding the source of

Table 2.—School-Level Analysis of Take-Up of DFS

	DFS present in the kitchen (1)	Salt delivered by the project team (2)	Change in food color (3)
Treat × Post	0.926^{***}		
	(0.036)		
Treat		0.617^{***}	0.369^{***}
		(0.070)	(0.067)
School-level controls	No	Yes	Yes
School fixed effects	Yes	No	No
Block fixed effects	No	Yes	Yes
Observations	214	107	107

Robust standard errors are presented in parentheses. Column 1 reports estimates from the DD regression model, while columns 2 and 3 report results from the SD regression model using the endline data only. School controls include school enrollment, class size, and student-teacher ratio. Significant at ***1%.

Table 3.—ITT Effects of the DFS Treatment on Hemoglobin Level and Anemia

	Hemoglobin (g/dL) (1)	Any anemia (2)	Mild anemia (3)	Moderate or severe anemia (4)
Treat × Post	0.185^{**}	-0.099^{***}	-0.053^{**}	-0.046
	(0.076)	(0.034)	(0.026)	(0.030)
Post	0.349^{***}	-0.123^{***}	-0.032^{*}	-0.091^{***}
	(0.055)	(0.029)	(0.019)	(0.023)
Mean of dependent variable, baseline	11.53	0.452	0.193	0.260
Observations	2,812	2,812	2,812	2,812

Robust standard errors, clustered at the school level, are reported in parentheses. The coefficients are based on a DD model estimated separately in each column. All columns include child fixed effects and time-variant household controls (household size, mother's and father's years of schooling, and asset index) and school-level controls: total enrollment, class size, and student-teacher ratio. The asset index was generated using the first component of the principal component analysis consisting of several household assets. Any anemia is defined as a hemoglobin value < 11.5 g/dl; mild anemia is defined as a hemoglobin value ≥ 11 and < 11.5 g/dl; moderate/severe anemia is defined as a hemoglobin value < 11 g/dl. Significant at *10%, **5%, and ***1%.

delivery, we find that treatment increased the probability of salt delivery by the study team by 61.7 pp compared with the control group, which makes sense given that our study team was in charge of delivering the DFS to treated schools. Additional evidence on take-up and compliance comes from the data on the change in food color. About 43% of the treated school headmasters reported that the use of DFS changes the color of the food. We expect that food color did not change in the control schools because controls were not using DFS. The point estimate of the SD model in column 3 is positive and statistically significant, indicating DFS was used in the MDM preparation in the treatment schools. The overall results in table 2 indicate statistically significant evidence of program take-up and compliance.

Furthermore, the rightward shift in the Hb distribution in the post-treatment period and significant program impacts on Hb levels further indicate strong program compliance (figure A2). Otherwise, our intervention would not have shifted the Hb distribution to the right if there was no difference in iron levels in MDM between the treatment and control schools.

B. *ITT Effects of DFS on Anemia and Test Scores*

Results in table 3 show that the use of DFS in the school lunch increased Hb levels by 0.19 g/dL, or by 1.6% at mean Hb levels of 11.53 g/dL. The estimated impact is small compared to other studies, but it should be noted that our estimates are from the consumption of only one fortified meal in contrast to studies in which DFS was used in all meals. The effect size of DFS intervention in efficacy studies ranged from 0.5 g/dL in India to 1.6 g/dL in Morocco (Zimmermann et al., 2003; Nair, Goswami, Rajan, & Thakkar, 2013).

We next explore the impact of treatment on anemia prevalence. Column 2 indicates that treated students were 9.9 pp, or 22%, less likely to suffer from any form of anemia compared with control students. The treatment reduced mild anemia by 5.3 pp, or 27%, on average; however, the treatment effects were statistically insignificant for moderate or severe anemia. It is not surprising that all the effects on any anemia in column 2 are driven by the reduction in mild anemia, as any anemia is the sum of mild and moderate to severe anemia, by construction.

The effect size of DFS impacts varies substantially across studies. The varied findings could be due to differences in the treatment duration (ranging from 2 to 18 months), sample size (ranging from 54 to 500 children), age structure of the sample (children 5 to 15 years of age), treatment intensity (dosage of iron in the DFS), physiological needs of the children (growth spurts among children increase iron need), and infectious disease burden. Infectious disease burden caused by malaria, hookworm, or other intestinal parasites affects iron absorption in the body. Therefore, DFS is less likely to have protective effects in malaria-prone or worm-infested areas due to the lower ability of the body to absorb iron. Additionally, treatment intensity varied considerably across studies; it ranged from 3 to 15 mg of iron intake per day.

The statistically insignificant effects on severe/moderate anemia may be due to the low intake of iron relative to the daily iron requirement for these children, as Diosady et al. (2019) note that DFS is effective for (mildly) anemic individuals who are close to the anemia cutoff. Since children in the treated schools received approximately 3.5 mg of iron compared to the daily requirement of 10 mg, such a low dosage may not be effective in improving the health of severely anemic children. Furthermore, the power calculation results in appendix table A5 show that our study lacked the power to detect significant effects on severe anemia.

We now turn to examine the impacts of DFS on cognitive and educational outcomes in table 4. Columns 1 to 5 in panel A measure the impact on several types of cognition tests, and column 6 measures the impact on the cognitive index, constructed using the PCA method on outcomes in columns 1 to 5. We do not find statistically significant treatment effects on any measures of cognitive outcomes. The point estimates are positive for all outcomes except for block design and digit span forward, although none of them are statistically significant. The cognitive index increased by 0.047 (95% CI: −0.011–0.20) due to the treatment, but the results are statistically insignificant (column 6).

Panel B further shows that the treatment had no significant impacts on math scores, reading scores, or attendance. The program increased the math score by 0.133 standard

TABLE 4.—ITT EFFECTS OF THE DFS TREATMENT ON COGNITION, TEST SCORES, AND CHILD ATTENDANCE

	Block design (1)	Digit span forward (2)	Digit span backward (3)	Progressive matrices (4)	Day and night (5)	Cognitive index (6)
Panel A						
Treat × Post	−0.021	−0.058	0.057	0.056	0.133	0.047
	(0.079)	(0.070)	(0.087)	(0.098)	(0.092)	(0.078)
Post	0.425***	0.524***	0.442***	0.189**	0.339***	−0.005
	(0.054)	(0.049)	(0.062)	(0.077)	(0.065)	(0.057)
Mean of dependent variable, baseline	0.048	0.030	0.033	−0.020	0.000	−0.041
Observations	2,790	2,790	2,790	2,790	2,790	2,790

	Math test score (1)	Reading test score (2)	Attendance (3)
Panel B			
Treat × Post	0.133	0.120	−0.002
	(0.085)	(0.077)	(0.022)
Post	1.019***	0.630***	−0.058***
	(0.054)	(0.054)	(0.016)
Mean of dependent variable, baseline	−0.007	−0.019	0.766
Observations	2,790	2,790	2,640

Robust standard errors, clustered at the school level, are reported in parentheses. Coefficients are based on a DD model estimated separately in each column. All outcomes, except school attendance, are normalized with reference to the baseline mean in the control group. The sample size for attendance is smaller due to missing and inaccurate attendance records for some children. All regressions include child fixed effects and time-variant household and school-level controls reported in table 3. Significant at *10%, **5%, and ***1%.

deviations (95% CI: −0.04–0.30) and reading score by 0.12 standard deviations (95% CI: −0.03–0.27). Surprisingly, the point estimate for attendance is negative (−0.002; 95% CI: −0.044–0.041), although it is neither statistically nor economically significant. The point estimate is quite small and precisely estimated, and due to a tight confidence interval, even a slight change in attendance could be rejected. We speculate that the null impacts on the learning outcomes could be due to low power, low treatment duration, or low dosage of iron in the DFS.

The zero impacts on attendance contrast with the findings in Miguel and Kremer (2004) and warrant some discussion. The authors of the deworming study argued that Kenyan children were at the margin of attending school due to heavy worm infestation, and a deworming program helped these marginal children attend school. It seems that the high worm infections were hindering school participation in Kenya, and the effective worm treatment significantly improved the health of these marginal children (the average impact size was about a 30% to 35% reduction in infections), which may have led to higher school participation. The authors speculate that anemia may not have played a role in improving school attendance, as the anemia rate in the Kenyan study was low (less than 4%).

In contrast, we argue that children in our study region were not marginal in terms of school participation, as the worm infection rate is quite low, and for them, neither worm infection nor anemia was a barrier to school participation participation, which is affirmed by the high attendance rate (76% on average). This is further corroborated by the lack of correlation between attendance rate and Hb levels; mild and severely anemic children had a similar likelihood of attending schools. Lack of difference in school attendance across the Hb spectrum suggests that anemic children were not too sick to miss school, but iron deficiency may have affected their attention span and concentration in classrooms. Furthermore, it is likely that at an average baseline Hb level of 11.5 g/dL, a 0.19 g/dL increase in Hb may have been too small to have an impact on school attendance.

C. *Heterogeneous Treatment Effects of the DFS Intervention on Anemia and Cognition*

Presentation of the average treatment effects in tables 3 and 4 implicitly assumes that the ITT impacts are the same for all students; however, program impacts may vary by children's characteristics. For example, one can suppose that the intensity of treatment increases with child attendance; students who attended schools more regularly during the treatment period consumed MDM more frequently and therefore would have higher exposure to the treatment. The school attendance rate in our sample ranged from 0 to 99% and the average attendance rate is 76.6% (figure A3). To investigate the heterogeneity in the treatment effect by attendance, we estimate equation (1) separately for attendance subgroups. First, we estimate the program impacts for subgroups with 70%, 80%, and 90% attendance rates. These cutoffs were guided by the lack of sufficient observations and variation in the sample with less than 50% attendance. To complement heterogeneity analyses by these cutoffs, we additionally used attendance terciles.

Panel A in table 5 shows that the health impacts of the DFS intervention tend to increase with higher school attendance, although the coefficients are not significantly different from each other. The hemoglobin and anemia results at 90% attendance are almost double the effects for the 70% attendance

TABLE 5.—HETEROGENEOUS TREATMENT EFFECTS ON HEALTH OUTCOMES, BY CHILD ATTENDANCE RATE

	Hemoglobin (g/dL) (1)	Any anemia (2)	Mild anemia (3)	Moderate or severe anemia (4)
Panel A				
Treat × Post (70% attendance)	0.217^{**}	-0.126^{***}	-0.065^{*}	−0.061
	(0.103)	(0.047)	(0.034)	(0.039)
Observations	1,878	1,878	1,878	1,878
Treat × Post (80% attendance)	0.233^{*}	-0.113^{**}	−0.033	-0.081^{*}
	(0.137)	(0.059)	(0.038)	(0.046)
Observations	1,220	1,220	1,220	1,220
Treat × Post (90% attendance)	0.391^{**}	-0.175^{**}	-0.108^{**}	−0.068
	(0.191)	(0.073)	(0.054)	(0.062)
Observations	490	490	490	490
Panel B				
Treat × Post (Bottom tercile)	0.120	−0.051	−0.046	−0.005
	(0.108)	(0.057)	(0.044)	(0.044)
Observations	952	952	952	952
Treat × Post (Middle tercile)	0.244^{**}	-0.121^{**}	−0.058	−0.063
	(0.105)	(0.054)	(0.048)	(0.048)
Observations	924	924	924	924
Treat × Post (Top tercile)	0.197	-0.118^{*}	−0.057	−0.061
	(0.157)	(0.067)	(0.044)	(0.054)
Observations	904	904	904	904

Robust standard errors, clustered at the school level, are reported in parentheses. Each cell reports DD coefficients from a separate regression. All regressions include child fixed effects and time-variant household and school-level controls reported in table 3. Any anemia is defined as a hemoglobin value < 11.5 g/dl; mild anemia is defined as a hemoglobin value ≥ 11 and < 11.5 g/dl; moderate to severe anemia is defined as a hemoglobin value < 11 g/dl. Significant at *10%, **5%, and ***1%.

TABLE 6.—HETEROGENEOUS TREATMENT EFFECTS ON COGNITION AND TEST SCORES, BY CHILD ATTENDANCE RATE

	Block design (1)	Digit span forward (2)	Digit span backward (3)	Progressive matrices (4)	Day and night (5)	Cognitive Index (6)	Math test score (7)	Reading test score (8)
Panel A								
Treat × Post (70% attendance)	0.025	−0.092	0.032	0.104	0.188^{*}	0.073	0.151	0.168^{*}
	(0.094)	(0.086)	(0.094)	(0.103)	(0.104)	(0.087)	(0.094)	(0.094)
Observations	1898	1898	1898	1898	1898	1898	1898	1898
Treat × Post (80% attendance)	0.059	−0.058	0.048	0.017	0.344^{***}	0.122	0.224^{**}	0.220^{**}
	(0.102)	(0.107)	(0.106)	(0.115)	(0.119)	(0.095)	(0.113)	(0.109)
Observations	1234	1234	1234	1234	1234	1234	1234	1234
Treat × Post (90% attendance)	0.175	−0.092	−0.120	0.004	0.424^{***}	0.120	0.271^{*}	0.361^{**}
	(0.146)	(0.130)	(0.142)	(0.146)	(0.142)	(0.105)	(0.142)	(0.159)
Observations	504	504	504	504	504	504	504	504
Panel B								
Treat × Post (Bottom tercile)	−0.115	−0.045	0.071	−0.032	0.032	−0.026	0.092	0.039
	(0.116)	(0.105)	(0.146)	(0.140)	(0.127)	(0.124)	(0.121)	(0.114)
Observations	938	938	938	938	938	938	938	938
Treat × Post (Middle tercile)	−0.086	−0.079	−0.018	0.154	0.080	0.009	0.082	0.062
	(0.118)	(0.112)	(0.127)	(0.139)	(0.123)	(0.103)	(0.117)	(0.127)
Observations	938	938	938	938	938	938	938	938
Treat × Post (Top tercile)	0.131	−0.085	0.090	0.057	0.323^{**}	0.151	0.224^{**}	0.272^{**}
	(0.116)	(0.116)	(0.121)	(0.131)	(0.127)	(0.099)	(0.112)	(0.125)
Observations	886	886	886	886	886	886	886	886

Robust standard errors, clustered at the school level, are reported in parentheses. Each cell reports DD coefficients from a separate regression. All outcomes are normalized with reference to the baseline mean in the control group. All regressions include child fixed effects and time-variant household and school-level controls reported in table 3. Significant at *10%, **5%, and ***1%.

group. There is less of a consistent pattern in results in panel B. The treatment effects are insignificant in the bottom tercile but significant for Hb level and anemia outcome in the middle tercile. The point estimates for Hb in the middle and top terciles are larger than the estimate in the overall sample in table 3, although it is significant only in the middle tercile. There is a 0.2 g/dL increase in the Hb level and reduction in any anemia by 12 pp among children in the middle tercile.

Table 6 reports the heterogeneous treatment effects on cognition and test score by attendance levels. There is a clear pattern of increasing treatment effects by attendance for day

Table 7.—Heterogeneous Effects by Gender and Baseline Anemic Status

	Hemoglobin (g/dL) (1)	Any anemia (2)	Mild anemia (3)	Moderate or severe anemia (4)
Panel A				
Female				
Treat × Post	0.231^{**}	-0.116^{***}	−0.055	−0.061
	(0.092)	(0.040)	(0.033)	(0.041)
Observations	1,552	1,552	1,552	1,552
Male				
Treat × Post	0.131	−0.082	−0.052	−0.031
	(0.105)	(0.054)	(0.043)	(0.035)
Observations	1,260	1,260	1,260	1,260
Panel B				
Anemic (Hb < 11.5 g/dL)				
Treat × Post	0.078	−0.041	−0.047	0.005
	(0.109)	(0.045)	(0.052)	(0.052)
Observations	1,272	1,272	1,272	1,272
Moderately anemic (Hb < 11 g/dL)				
Treat × Post	0.215	−0.074	0.001	−0.076
	(0.140)	(0.061)	(0.036)	(0.053)
Observations	730	730	730	730
Nonanemic (Hb > 11.5 g/dL)				
Treat × Post	0.091	−0.005	0.009	−0.014
	(0.075)	(0.028)	(0.021)	(0.019)
Observations	1,540	1,540	1,540	1,540

Robust standard errors, clustered at the school level, are reported in parentheses. Each cell reports the DD coefficient from a separate regression. All regressions include child fixed effects and time-variant household and school-level controls reported in table 3. Any anemia is defined as a hemoglobin value < 11.5 g/dl; mild anemia is defined as a hemoglobin value ≥ 11 and < 11.5 g/dl; moderate to severe anemia is defined as a hemoglobin value < 11 g/dl. Significant at *10%, **5%, and ***1%.

and night, math, and reading scores in panel A. The treatment effect for day and night at 90% attendance is more than double the effect at 70% attendance (0.188 versus 0.424). Similarly, the treatment effects on math and reading scores are significant and higher at 80% and 90% attendance compared with the impact size at 70% attendance. The results in panel B show evidence of an attendance gradient for the three outcomes: day and night, math, and reading score; however, estimates are statistically significant only in the top tercile. None of the coefficients in the bottom and middle terciles are statistically significant at the conventional level of significance. As discussed before, the insignificant effects on the learning outcomes could be due to low power (table A5), and therefore these results should be interpreted with caution. Our study was sufficiently powered to detect small effects on Hb and mild anemia but was inadequately powered to detect large impacts on learning outcomes.

In addition to 70%, 80%, and 90% cutoff and tercile-based heterogeneity, we further explore the heterogeneous treatment effects for the key outcomes at the full distribution of attendance (figure A4). We report these graphs for the outcomes for which we detected significant heterogeneous effects by child attendance rate. For cognitive and test score outcomes, these graphs suggest increasing treatment effects by attendance rate and show that the heterogeneous treatment effects by attendance are mostly driven by the higher distribution of attendance (greater than 80%), which is consistent with the heterogeneous findings in tables 5 and 6. Results at the lower attendance level are insignificant, as the confidence band includes 0.

Table 7 shows the heterogeneous estimates by gender and the baseline anemic status of children. Results show that the intervention brings greater and statistically significant health improvements to girls compared to boys. The Hb levels of female students in the treated schools improved by 0.23 g/dL and anemia reduction by 11.6 pp compared with female students in the control schools, while the point estimates are smaller and insignificant for male students. However, the treatment effects do not differ significantly between girls and boys for the health outcomes ($p = 0.49$ for Hb and $p = 0.85$ for any anemia). Although biological needs for iron do not differ by gender in the preadolescent years, this is an important finding given that previous studies found no differential impacts on Hb levels by gender (Luo et al., 2012; Banerjee et al., 2018).

Biological plausibility implies that iron supplementation should lead to larger gains for severely anemic children at baseline compared with less- or non-anemic children (Thomas et al., 2006). To examine the potential heterogeneity by baseline anemic status, we divide the sample into three groups: nonanemic (Hb > 11.5 g/dL), anemic (Hb < 11.5 g/dL), and moderately anemic (Hb < 11 g/dL). We do not find evidence of heterogeneity on the initial Hb level (panel B of table 7). This is somewhat surprising, but these results are similar to findings in two recent studies conducted in India (Banerjee et al., 2018; Berry et al., 2019) and in China (Wong et al., 2014). One explanation could be that the low-Hb children are more likely to miss school and therefore consume fewer meals and benefit less from the treatment. However, figure A5 shows that this is unlikely, as there is not much

TABLE 8.—SCHOOL-LEVEL HETEROGENEITY, BY SCHOOL ATTENDANCE RATE

	Hemoglobin (g/dL) (1)	Any anemia (2)	Mild anemia (3)	Moderate or severe anemia (4)
A: Above-mean school attendance				
Treat × Post	0.215^{*}	-0.140^{**}	-0.082^{**}	−0.059
	(0.127)	(0.055)	(0.038)	(0.047)
Observations	1270	1270	1270	1270
B: Below-mean school attendance				
Treat × Post	0.129	−0.048	−0.023	−0.025
	(0.090)	(0.042)	(0.033)	(0.043)
Observations	1,542	1,542	1,542	1,542

Robust standard errors, clustered at the school level, are reported in parentheses. All regressions include child fixed effects and time-variant household and school-level controls reported in table 3. Any anemia is defined as a hemoglobin value < 11.5 g/dl; mild anemia is defined as a hemoglobin value ≥ 11 and < 11.5 g/dl; moderate to severe anemia is defined as a hemoglobin value < 11 g/dl. Significant at *10%, **5%, and ***1%.

correlation between child attendance and baseline Hb levels. The more plausible reason could be that the low dosage of iron in the DFS and low treatment intensity (only one fortified meal per day) may not be beneficial for the severely anemic children, as discussed above.

It is possible that the estimated heterogeneity in impacts by school attendance in tables 5 and 6 may be confounded by school quality, which is unobserved. For example, high-quality schools may have higher attendance as well as better program compliance and implementation.[3] To explore school-level heterogeneity in the program impacts, we estimate heterogeneous treatment effects in two subgroups defined by attendance at the school level instead of the child attendance rate: (a) high-attendance schools (school attendance higher than the average) and (b) low-attendance schools (school attendance lower than the average).[4] Results in table 8 show that the program impacts are higher among high-attendance schools than low-attendance schools, but the difference is statistically insignificant ($p = 0.46$ for Hb and $p = 0.11$ for any anemia). The program increased Hb levels by 0.22 g/dL and reduced anemia by 14 pp in the high-attendance schools but point estimates for low-attendance schools are smaller and statistically insignificant. These results confirm that the heterogeneous results in tables 5 and 6 are driven by child attendance and not by unobserved school characteristics.

We further examine whether the treatment effects for high-attendance students differ between high and low school attendances. The statistically insignificant results in table A6 imply that keeping school quality constant, the difference in the effects between high- and low-attendance students is not statistically significant (column 1). Furthermore, treatment effects for high-attendance students do not differ significantly between high- and low-attendance schools (column 1 versus column 2: −0.003 versus −0.046). These results imply that controlling for the attendance of the child, school-level attendance (a proxy for school quality) does not affect the outcomes.

D. *Potential Attendance Endogeneity*

One can imagine that school attendance may be endogenous, as it is likely to be affected by the treatment through either behavioral channels or health improvement channels. Therefore, conducting the heterogeneity analyses by attendance may bias our findings. We attempt to address these concerns below, but we acknowledge that our attendance results should be interpreted with a grain of salt. The behavioral change (e.g., if parents were aware of the treatment, they might send their children to schools more often to consume DFS) is unlikely to affect attendance because our double-blind study design ensured that neither parents nor children were aware of the intervention. Although parents were unaware of the intervention, attendance may have been affected if treatment improved health (Miguel & Kremer, 2004). In contrast, anemic children may also have missed schools frequently and therefore would less likely be affected by the treatment, so treatment is likely to change the composition of children through health channels. We performed several tests to check for these possibilities and find that child attendance is not affected by the treatment (column 3, panel B, table 4) or the initial Hb level of children (table A7); hence, attendance is less likely to be endogenous. The coefficient in table A7 shows that baseline anemic indicators are not significantly associated with attendance. Figure A5 suggests that child attendance is not increasing in baseline Hb levels; the line is almost flat and does not change as the Hb level increases. The correlation between baseline Hb and endline attendance is 0.01. Not only is the average treatment effect on attendance insignificant, but the quantile treatment effects are also insignificant (figure A6). The treatment had insignificant impacts on attendance for different subgroups in table A8. Unlike parasitic worms, it seems anemia is not a significant barrier to school participation in our setting, and even low-Hb children attend schools frequently and thus were well exposed to the treatment. These findings reduce the concerns about attendance endogeneity.

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[3] All regressions always control for school-quality measures: total enrollment, class size, and student-teacher ratio.

[4] School attendance rate was aggregated from child attendance rate during the intervention period. The correlation between the two is 0.44.

TABLE 9.—ROBUSTNESS TO ATTRITION AND SCHOOL ATTENDANCE CONTROL

	Hemoglobin (g/dL) (1)	Hemoglobin (g/dL) (2)	Any anemia (3)	Any anemia (4)	Mild anemia (5)	Mild anemia (6)	Moderate or severe anemia (7)	Moderate or severe anemia (8)
Treat × Post	0.184**	0.186**	−0.097***	−0.099***	−0.052**	−0.053**	−0.045	−0.046
	(0.076)	(0.076)	(0.034)	(0.035)	(0.026)	(0.026)	(0.0304)	(0.030)
Post	0.392	0.353***	−0.308**	−0.126***	−0.119	−0.034*	−0.189*	−0.093***
	(0.257)	(0.055)	(0.118)	(0.029)	(0.090)	(0.20)	(0.101)	(0.024)
School attendance control	Yes	No	Yes	No	Yes	No	Yes	No
Attrition weights	No	Yes	No	Yes	No	Yes	No	Yes
Observations	2,812	2,812	2,812	2,812	2,812	2,812	2,812	2,812

Robust standard errors, clustered at the school level, are reported in parentheses. Estimated coefficients are based on a DD model estimated separately in each column. Any anemia is defined as a hemoglobin (Hb) level < 11.5 g/dl; mild anemia is Hb ≥ 11 and < 11.5 g/dl; moderate/severe anemia is Hb < 11 g/dl. All regressions include child fixed effects and time-variant household and school-level controls reported in table 3. School attendance control is from endline. Significant at *10%, **5%, and ***1%.

E. *Robustness Checks*

We perform two robustness checks to strengthen our main findings. First, although we control for school characteristics in all models, we additionally control for school-level attendance to further address the concern that school quality, proxied by school attendance, is not confounding the results. We find that our results are robust to controlling for the school-level attendance rate (see table 9).

Second, although there is no evidence of selective or differential attrition, we weight equation (1) with attrition weights and estimate an inverse probability weighted regression. The attrition weights are estimated using the baseline characteristics of the children who are likely to affect attrition propensity. With the inclusion of inverse probability weights, the treatment effects of the DFS intervention remain unchanged and are almost identical (table 9). The point estimates are almost unchanged compared with the main results in table 3. Overall, the results in table 9 show that our main findings are robust to sample attrition and school quality.

VII. Potential Sources of Bias

One potential concern that may bias our main results is leakage or resale of DFS. If some schools did not use the DFS and instead sold it to the control schools or households for financial gain, the main findings will be biased. The first-stage results in table 2 on DFS use and low demand for DFS in the study region rule out the possibility of resale of DFS. Also, since salt is an inexpensive product, the financial incentive for reselling DFS is quite small. In the follow-up survey, a negligible proportion of 0.28% of the households reported having used DFS, and none of the control schools reported DFS use during the intervention period.

Another concern is if children from control schools transferred to treatment schools to benefit from the treatment. This is unlikely to happen because every village is zoned to a specific public primary school and students are not allowed to transfer to schools that are not assigned to their village. Attending a school in another village and transfers across schools are extremely uncommon in rural areas. Our double-blind type of intervention ensured that parents were unaware of the intervention. This is further confirmed in the survey data; only one-fourth of the survey respondents had heard of iron in the food; thus, the possibility of sending children to a treatment school to benefit from the intervention is quite remote.

The introduction of other concurrent programs such as iron and folic acid supplementation could also have biased the DFS impacts. The government of India launched the nationwide "weekly iron and folic acid supplementation program" (WIFS) in 2012, targeting 108 million adolescent girls and boys. However, despite the federal launch of the program, WIFS was not implemented in Bihar until January 2019 and therefore is unlikely to have contaminated the true effects of the DFS intervention in our study. Furthermore, district-level education and health officials and headmasters also confirmed that no iron supplementation program including WIFS was implemented in the sampled schools during the study period.

A. *Hawthorne Effect*

Another issue of concern may be the Hawthorne effect—changes in the behavior of the control children in response to being part of the DFS experiment. In other words, knowledge of being in the treatment group could have caused children to modify their behaviors in ways that may affect the outcomes. But the double-blind RCT design rules out this possibility. Since only headmasters were aware of the intervention, this behavioral change would be limited to headmasters only. Neither the parents nor the children were aware of the DFS intervention, so it is unlikely that they would have changed their behaviors to benefit from the intervention (e.g., attend school more frequently to consume MDM; recall that treatment had no effect on attendance). Nevertheless, we analyzed the impact of the treatment on the household dietary diversity score (DDS), which can be an indirect test to capture the behavioral change in household diets. The treatment had a negative and statistically insignificant effect on the dietary pattern of the households (table A9), corroborating a lack of behavioral change at the household level.

Furthermore, schools may adjust the lunch menu to address anemia among students if students showed symptoms of anemia in school (even though headmasters were not informed of the anemic status of the students as part of the experiment). However, we believe this is unlikely because the MDM menu is set by the state government and schools do not have the authority to change it. Second, schools lack resources to buy food items other than the menu set by the state. Finally, symptoms of anemia are not fatal and are not easily recognizable by nonmedical people, so it is unlikely that headmasters or teachers would have reacted to anemic symptoms among children in their schools. Furthermore, school staffs were not trained to recognize symptoms of anemia and were not aware of the anemic status of the students. Therefore, we believe that the Hawthorne effect is less likely to be a concern in this study.

B. Attenuation Bias

As part of the Institutional Review Board protocol, we had to inform parents if their child was moderately or severely anemic and to advise them to include iron-rich food items in their diet or consult doctors. Parents' reactions to this information could confound our results. Since this information intervention was not implemented differentially across the treated and control groups, its effect is therefore balanced between the two groups. However, in case the information intervention led to a change in feeding practices or medical treatment, a saturation effect might have occurred (i.e., decreasing returns to scale of iron interventions) that could downward bias our main findings. However, in a robustness check, we find that our main results are robust to the specification that includes children's DDS as an additional control variable (results available on request). Furthermore, in a companion paper, we explore the effect of the nutrition information intervention with a regression discontinuity design and did not find significant effects on any of the outcomes explored in this study, indicating that the nutrition information did not lead to attenuation bias (Krämer, Kumar, & Vollmer, 2021). The empirical design in the companion paper exploited the discontinuity at the "severe anemia" level of 11.0g/dl. Children who were below this cutoff received the nutrition information treatment and children above the cutoff served as the control group. We find that nutrition information treatment had no significant effect on household dietary behavior, anemia, or cognitive outcomes of children.

There might be additional concerns that teachers may have consumed MDM and become less anemic, and this could have affected their teaching ability, thus improving the scores of the children on the cognitive tests. Unfortunately, our study did not collect information on the anemic status of teachers, but we believe such an effect is not likely for several reasons. First, anemia prevalence is not that high among teachers; the anemia rate among male adults in India is about 20% (IIPS & ICF, 2017). Therefore, it is unreasonable to believe that lack of Hb was affecting teachers' ability to teach effectively. Second, since we did not find any significant impacts on students' cognition, we believe the impacts of DFS on teachers' abilities would be limited. Third, school survey results suggest that only a small proportion of teachers consumed MDM at school; most brought lunch from home. Therefore, we believe that this channel is unlikely to bias the DFS impacts in this study.

C. Cost-Effectiveness Analysis

We provide a back-of-the-envelope calculation to illustrate the cost-effectiveness of the DFS intervention, which will enable policymakers to compare it with other micronutrient interventions. In total, we spent approximately INR 332,000 (US$ 4,887) on the one-year intervention. The cost of the intervention consists of the cost of the DFS subsidy (we received the DFS from the manufacturer for INR 20.04 per kilogram and provided it for INR 12 per kilogram to the headmasters, a subsidy of 40%) and the costs of delivering DFS to schools. The subsidy accounts for approximately INR 106,000 (US$ 1,560) and the distribution for approximately INR 226,000 (US$ 3,327). The intervention in the 54 schools reached almost 14,000 children (because all children in the school benefited from the iron-fortified lunch, not only those that took part in the study), such that the cost per child was about INR 24 (US$ 0.35). With an expenditure of slightly more than US$ 100, we provided DFS to about 300 children (average size of school), and, based on the estimated treatment effects in table 3, eighteen cases of anemia—six moderate or severe and twelve mild cases—were averted.

Applying the disability weights for mild (0.004) and moderate or severe (0.052) anemia, this sums to 0.36 disability-adjusted life-years (DALYs) averted (Murray & Lopez, 2013). One DALY averted would therefore cost approximately US$ 280. The World Health Organization assesses interventions as very cost-effective if the cost per DALY averted is less than the GNI per capita of the country where the intervention is going to be implemented (Sachs, 2001). India's GNI per capita at purchasing power parity in 2015 was US$ 6,030 (World Bank, 2017), which means that our DFS intervention is very cost-effective in terms of cost incurred per DALY averted. Our estimate is a very conservative assessment of the cost-effectiveness of the intervention because it does not account for the potential long-term effects of the intervention: effects on other outcomes such as education and wages and the possibility of benefiting from economies of scale if included in existing distribution infrastructure.

VIII. Discussion and Policy Implications

This paper presents new experimental evidence on the impacts of a school-based DFS intervention on anemia and learning outcomes of children. We use a school lunch program as a potential delivery channel to provide iron to schoolchildren to address iron deficiency in rural Bihar. We find that DFS provided through the MDM improved the anemic status of children. Despite the health improvement, the average impacts on cognition and learning outcomes were insignificant; however, when we analyze the heterogeneity by child attendance, there is evidence of a dose-response type of gradient in the improvement of Hb levels as well as test scores with an increase in child attendance.

Our findings have important policy implications. This study demonstrates that a school-based DFS intervention can be effective in reducing anemia by ensuring higher and consistent take-up. Previous interventions have suffered from low take-up of micronutrients (Banerjee et al., 2018) and had to adopt encouragement design, instruct teachers, or add an extra layer of supervision to increase take-up (Bobonis et al., 2006; Thomas et al., 2006; Chong et al., 2016). One central difference between the delivery channel used in our experiment and the study by Banerjee et al. (2018) is that DFS use was mandatory in our study (at least on the part of the children through the decision by their headmasters and the school authorities to participate in the study and use DFS for the midday meal), whereas in Banerjee et al. (2018), participation was voluntary and consumers were given the option of buying the fortified product. The positive effects from our study reflect the potential advantage of mandatory fortification where a behavioral change in dietary patterns at the household level seems difficult to attain.

However, the low dosage of iron in the salt and restriction of its provision to one fortified meal a day also has implications for the intervention's limited effects on moderately or severely anemic children. The average change in the Hb level in our study is +0.19 g /dL, which implies that the DFS intervention through the school meal could be effective in reducing anemia for mildly anemic children rather than for severely anemic children; additional resources or medical interventions are needed to address low Hb levels among severely anemic children. Diosady et al. (2019) noted that the effectiveness of DFS depends on how close individuals are to the anemia borderline (Hb = 11.5 g/dL), as DFS is fortified to meet 30% to 50% of the daily iron requirement. Therefore, the school-based DFS program should be complemented with additional resources and strategies such as a take-home ration, DFS use in home cooking, food fortification, and iron supplementation to help achieve better health outcomes for severely anemic children.

Some limitations of this study that might restrict our ability to interpret the findings merit attention. First, although our study sample is representative of school-age children attending government primary schools in rural Bihar, further replications of this study in other settings would enrich the evidence base on this topic. Our study team developed a strong and trusting relationship with the headmasters, and the intervention was strongly supported by the local government, which might not be the case in other settings.

Second, our study is unable to address the problem of anemia among pregnant women, older girls, out-of-school children, and children attending private schools. Recent data reported an anemia prevalence of 54% among pregnant women in India (IIPS & ICF, 2017). A health facility-based supplementation program during antenatal care visits or through frontline health workers (Anganwadi) may be a more effective strategy to address anemia among pregnant women. For other subgroups, alternative strategies such as take-home rations (successful in Africa), food fortification, diet diversification, weekly iron and folic acid supplementation, and home delivery of DFS might be more effective than a school-based DFS program. The school-based DFS intervention, however, could still address the anemia problem among a sizable proportion of adolescent girls and boys because the MDM scheme has been extended to upper primary schools to cover children 6 to 14 years of age. Also, for children attending private schools, DFS intervention through MDM may have limited impacts because private schools usually do not serve meals. However, the private school participation rate in rural areas is quite low—20% and 10% in India and Bihar, respectively (NSS, 2014–2015)—and children attending private schools usually come from better-off households and are less likely to be anemic due to a higher socioeconomic status.

Third, the low dosage of iron in the DFS and the short duration of the treatment warrant some discussion. Though we could not find statistically significant effects on the cognitive tests and the evidence for positive effects on educational outcomes showed up only at higher levels of school attendance, it might very well be the case that these effects indeed exist but need a longer time to materialize. Several field-based nutritional studies show that when DFS is used in all meals, cognitive impacts appear after nine to ten months (Wenger et al., 2017). Children in our study consumed only one meal at school, and therefore we speculate that steady use of DFS for at least 24 months may have impacts on the cognitive functions of children.

Furthermore, it is also possible that these children are deficient in multiple micronutrients (vitamin A, vitamin B, and zinc) or are suffering from helminths and malarial infections. In that case, iron supplementation through DFS alone may not have impacts on anemia and educational outcomes. The absorption of iron depends not only on its actual content but also on other micronutrients, helminths, or malarial infections. That is why several studies combined iron supplementation with deworming tablets or added other micronutrients to provide better efficacy of iron supplementation (Bobonis et al., 2006; Thomas et al., 2006). We therefore believe that future studies should attempt to explore the longer-term effects of the DFS intervention alone, as well as of multiple micronutrient interventions with different variations in iron dosage and treatment duration.

It is also worth discussing how generalizable the findings of this study are and who could eventually be reached with the intervention studied in this paper. Given the random selection of the sample, the study sample is representative of the rural population in the district as well as Bihar, and we believe our findings could be extended to other similar settings where public schools are the dominant provider of primary education and school meal programs are operational.

National school lunch programs worldwide serve as many as 380 million school children daily, and 120 million meals are served in India alone. Globally, anemia affects one out of four school children (305 million; WHO, 2016). Our intervention, being low-cost and scalable, offers huge promise in addressing anemia among school children.

Our study is limited in that it includes only children attending public schools and omits children attending private schools. About 90% of primary school-age children in rural areas attend government schools in Bihar (NSS, 2014–2015), and therefore, when scaled up statewide to cover MDM in all primary and upper primary schools in Bihar, the DFS intervention could potentially reach approximately 10 million children daily and can effectively reduce childhood anemia. This could be achieved at a minimal additional cost, as the MDM scheme is operational in 98% of government schools in Bihar. The positive results of our study provide a solid evidence base for scaling up DFS programs in schools to combat childhood anemia worldwide.

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