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The effect of Universal Salt Iodization on cognitive test scores in rural India

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ABSTRACT

This paper studies the impact of a large-scale public health intervention in early life on cognitive skills in childhood. Iodine deficiency is the most common predictor of brain damage globally which has prompted over 140 countries to implement Universal Salt Iodization. While small-scale interventions report positive effects of iodine supplementation on cognition, the causal impact of salt iodization at scale is unknown across low-income countries. This study evaluates the effect of Universal Salt Iodization on cognitive test scores of school-aged children in rural India. I exploit exogenous variation in the timing of the exposure to the policy in early life, comparing children residing in naturally iodine sufficient and deficient districts over time, using a difference-in-differences strategy. Exposure to the program increased basic numeracy and literacy skills by at least 2.4 percentage points and improved school progression. It further raised literacy scores by 6.1% of a standard deviation for girls. The effects on test scores are higher for poor children and for those residing in, or nearby, the major salt producing state where iodized salt consumption was lower at baseline. This is the first study to show that a blanket fortification policy can deliver considerable, yet heterogenous, improvements in cognition in the medium run in a developing country context.

1. Introduction

Health in early life has been proven to have persistent impacts on human capital across the life-course, particularly in developing countries (Almond & Currie, 2011; Almond, Currie, & Duque, 2018; Berg, Lindeboom, & Portrait, 2006; Currie & Vogl, 2013). A growing literature demonstrates that exposure to public health interventions during a critical age does not only impact immediate health, but also schooling outcomes, productivity and earnings later in life, see Bleakley (2007), Cutler, Fung, Kremer, Singhal, and Vogl (2010), Spears and Lamba (2016) and Isen, Rossin-Slater, and Walker (2017). The observed long-term outcomes are often products of the accumulation of a variety of dimensions of human capital including health, cognitive- and non-cognitive skills over time (Attanasio, 2015). Cognition constitutes a particularly important aspect of human capital as it is a key driver of productivity and economic growth (Altinok & Aydemir, 2017; Madsen, 2016). However, little is known about the direct impacts of large-scale public health programs on cognitive skills in the medium run, particularly in developing countries (Almond et al., 2018).

Iodine deficiency in early life is the most common predictor of permanent and irreversible brain damage. The deficiency is more prevalent in low-income countries, particularly in South Asia and Sub-Saharan Africa (Aburto, Abudou, Candeias, & Wu, 2014). Universal Salt Iodization (USI) is a highly cost-effective policy which aims to eradicate iodine deficiency by covering at least 90% of the population with iodized salt (Zimmerman & Andersson, 2012). Therefore, USI constitutes a promising large-scale intervention to improve cognition. However, despite USI being implemented in more than 140 countries, it is not well understood whether such a blanket policy can raise cognitive skills, especially in developing countries. An abundance of small-scale RCTs show positive effects of iodine supplementation on cognition for certain populations (Bougma, Aboud, Harding, & Marquis, 2013). Existing evidence from low- and middle-income countries is only available for less common, targeted short-term supplementation programs (Bougma et al., 2013; UNICEF, 2015). Field, Robles, and Torero (2009) report that the provision of iodine capsules to pregnant women in Tanzania increased years of schooling for their children. Evaluating the same supplementation program using the same identification strategy, Araújo, Carrillo, and Sampaio (2021) show improvements in the completed years of education, predicted income and uptake of skilled jobs in adulthood. However, a replication of Field et al. (2009) by Bengtsson, Sävje, and

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Swartling Peterson (2019) finds no effects on schooling outcomes in childhood after improving the empirical strategy and including additional data.

Developing countries often have weak institutions and low supply and demand for preventative health products (Meredith, Robinson, Walker, & Wydick, 2013). In addition, universal food fortification relies on involvement of the private food industry as well as adequate infrastructure to reach poorer households who often depend on subsistence farming (Bishai & Nalubola, 2002). Such prerequisites are often lacking in low-income settings which could hinder uptake of fortified salt by key-populations and limit population-wide impacts (Neufeld, Baker, Garrett, & Haddad, 2017). On the other hand, developing countries have more to gain from successful USI implementation as they are home to the majority of children failing to reach their cognitive potential (Grantham-McGregor et al., 2007).

This paper addresses the question of whether USI has the capacity to improve children's cognitive skills in rural India. Despite unprecedented economic growth, India is home to around one-third of all malnourished children globally (Deaton & Angus, 2009). Moreover, learning outcomes have been stagnating in spite of the implementation of a range of education programs (Chatterjee, Li, & Robitaille, 2018). I apply difference-in-differences to analyze the effect of USI during early life on cognitive test scores, across naturally iodine deficient and sufficient districts over time. Given that the risk of iodine deficiency is mainly determined by geography, low iodine availability in the soil and groundwater is proxied by historical goiter endemicity which in turn identifies districts that are likely to benefit more from USI (Feyrer, Politi, & Weil, 2017; Hetzel, 2002).[1] Exposure to USI in utero until at least age 2, increases the probability of recognizing at minimum simple numbers or letters by at least 2.4 percentage points among rural primary school-aged children. Girls improved their literacy score, which also takes more difficult reading attainment into account, by 6.1% of a standard deviation, while no effects are found for boys. Additionally, grade progression improved for both genders. The policy succeeded in reaching poorer children as their cognitive test scores improved more than those from non-poor backgrounds.

The analysis benefits from a large data set on learning outcomes of both in- and out of school children from the Annual Status of Education Report (ASER). Thus, the results are not driven by changes to the composition of children attending school as the children are surveyed at home. Furthermore, the treatment effects hold in an event-study framework, after applying a triple-difference-in-differences exploiting distance to the major salt producing state as an additional source of exogenous variation, as well as using geographical characteristics as Instrumental Variables (IV) for baseline iodine deficiency. Further validity checks indicate that the treatment is not related to household or village characteristics or other coinciding improvements in health.

The vast literature concerned with the impact of salt iodization uses historical data from high income countries. Feyrer et al. (2017) estimate the effect of iodized salt availability in the US from the 1920's on the probability of being accepted into the cognitively more demanding Air Forces during World War II. They identify treatment status by the interaction of pre-existing goiter prevalence per military section, with year of birth. The results suggest an increase of 15 IQ points. Drawing upon the same natural experiment, Adhvaryu, Bednar, Molina, Nguyen, and Nyshadham (2020) show that salt iodization increases income, labor force participation and the probability of being in full-time employment. The gains were almost entirely driven by females. Similarly, Politi (2010a, 2010b) demonstrates that historical salt iodization in Switzerland increased schooling attainment and the probability of entering occupations with higher cognitive demands and wages. While historical experiences are useful to study long-run outcomes, the context differs from current government-led USI programs. The spread of iodized salt in the US was initiated and sustained by a few large salt producers on a voluntary basis, without any regulation, standardization or controls (Adhvaryu et al., 2020; Bishai & Nalubola, 2002). The proportion of households consuming iodized salt over time and its iodine content is unknown. Additionally, the uptake of fortified salt relied on marketing from private producers and on the demand from health conscious consumers which makes it difficult to rule out selection in take-up.

Recent papers show that USI increased school enrollment in China by 0.6 percentage points (Huang, Liu, & Zhou, 2020) and improved girls' test scores (Deng & Lindeboom, 2019). However, evaluations of the Chinese policy do not enhance our understanding of the potential impacts of USI across developing countries due to China's state monopoly on the production, distribution and sale of salt. This study shows that the organization of the salt market matters for the availability of iodized salt which in turn may lead to inequitable distribution in the absence of a national policy. USI had larger effects on both the consumption of iodized salt and cognitive skills for children residing in, or nearby, the major salt producing state compared to states further away. The predominance of many small and medium-sized producers for whom iodization is costly is a barrier to successful USI implementation in India and other developing countries. Other factors are weak enforcement and regulation, low quality of fortified products and the population being unaware of the benefits of iodine and (Kumar, Tiwari, & Gautam, 2013; Neufeld et al., 2017; Vir, 2003). Thus the effects of the Indian USI is likely to be externally valid for other low- and middle-income countries.

This paper also adds to our understanding of gender differences in the effects of iodine fortification. Field et al. (2009), Deng and Lindeboom (2019), Adhvaryu et al. (2020) and Huang et al. (2020) show that iodine supplementation only affects female human capital or that the effects are larger for women compared to men. This is in contrast to the large cognitive improvements for male draftees in Feyrer et al. (2017). The results from this study reconcile these findings by demonstrating heterogeneous effects by gender and learning outcomes. Basic numeracy skills improved for both genders while only girls' literacy scores, which include more difficult levels of attainment, increased after USI exposure. Deng and Lindeboom (2019) explain the lack of improvements for boys' following USI in China by son-bias enhancing the female disadvantage prior to the policy. This paper shows that the treatment effects are robust to variation in area-level gender preferences which suggests that USI is a powerful intervention to raise cognitive skills for children despite prevailing gender inequalities.

Moreover, this study presents more optimistic findings in line with the medical literature of the potential impact of access to fortified salt compared to recent randomized studies in India. Randomization of the provision and sale of salt fortified with iron and iodine in one of the poorest states in India, Bihar, did not affect infant development or child cognition (Banerjee, Barnhardt, & Duflo, 2018). Krämer, Kumar, and Vollmer (2020) also do not find any cognitive improvements among pupils after one year of adding double-fortified salt to school-meals. Thus, my study highlights the importance of access to fortified salt throughout early childhood. Cognitive skills have been shown to be impacted by various types of targeted nutrition programs in early childhood, often combined with parenting interventions or pyscho-social stimulation, and more recently as components within large-scale early childhood community-based programs (Black et al., 2017; Engle et al.,

[1] Iodine does not occur naturally in specific foods. Rather, it is the iodine availability in the soil which determines the crop's iodine level (Hetzel, 2002).

2011; Maluccio et al., 2009; Vikram & Chindarkar, 2020). In addition to targeted interventions, this study shows that USI has the potential to improve cognitive skills in a highly cost-effective manner.

The paper is organized as follows. In Section 2, the biological role played by iodine in the human body is reviewed. The context of the Indian USI policy is explained in Section 3, followed by a discussion of the data in Section 4. Section 5 presents the empirical strategy and the results. The robustness of the findings is discussed in Section 7 and concluding remarks are reported in Section 8.

2. Iodine deficiency and cognition

Iodine is needed to regulate thyroid hormone availability. The thyroid gland secretes 80 μg of iodine per day in the form of thyroid hormones. Thyroid hormones are released into the blood stream to control the metabolism of all cells in the human body. The WHO recommends the following daily iodine intake; 90 μg for children of 0–59 months, 120 μg for ages 6–12, 150 μg for older children and adults and 250 μg for pregnant and lactating women (Andersson, de Benoist, & Rogers, 2010).[2] On average, adults in India consume about 11 g of salt per day (Johnson et al., 2017). When the thyroid does not receive sufficient amounts of iodine, it becomes enlarged such that it can produce more thyroid hormones for a given level of iodine (Zimmerman, 2009). This condition is called goiter and has by itself no ill effects on health.

Normal concentrations of thyroid hormones are required for the development of the central nervous system during early life. The most critical time for overall brain development is during the fetal stage. Extreme fetal iodine deficiency can also lead to cretinism, deaf-mutism, abortions, stillbirths, congenital anomalies and increased perinatal and infant mortality (Zimmerman, 2012). There is abundant evidence of the association between iodine deficiency, including mild deficiency, and cognition (Lavado-Autric et al., 2003; Zimmerman, 2012). However, most medical and epidemiological literature involving humans is correlational.

A systematic review of a small number of high quality randomized controlled trials show that iodine supplementation in utero increases IQ with an average of 7.4 points (Bougma et al., 2013). The evidence of particularly critical time periods in utero is mixed. Clinical research shows that infant development is not affected if pregnant women who were previously iodine deficient during early gestation become sufficient later in pregnancy (Pop et al., 2003). A review conducted by Zoeller and Rovet (2004) concludes that thyroid hormones affect the developmental process in all areas of the brain which makes it difficult to identify specific critical time periods. Because different areas of the brain develop at different times, critical periods of iodine intake are temporally shifted. In addition, postnatal thyroid hormone insufficiency is associated with poorer language, auditory processing, attention, memory and fine motor skills (Zoeller & Rovet, 2004). The positive effect of iodine supplementation, including the consumption of iodized salt, does not appear to impact children aged 3 years or older (Aboud, Bougma, Lemma, & Marquis, 2017). The majority of medical studies involving humans does not show a gender differential in iodine sensitivity.[3]

Robust evidence on the impact of iodized salt on children's cognitive skills is scarce. A systematic review by Aburto et al. (2014) reports that the exposure to iodized salt in gestation, infancy and early childhood, in mildly to severely iodine deficient populations, reduces children's risk of low intelligence (defined as IQ $\leqslant$70) of 72–76% and increases IQ by 8.2–10.5 points. However, the review only includes quasi-experimental studies where the iodine content of salt is at least 20 μg/g salt. Moreover, the vast majority of the studies rely on comparing the impact of access to iodized salt across cohorts within Chinese localities. The only randomized intervention to study the impact of iodized salt consumption among pregnant women on children's cognitive outcomes is Mohammed, Marquis, Aboud, Bougma, and Samuel (2020). The authors find an improvement of around 4 IQ points for children aged 2–13 months after providing high quality iodized salt with at least 15 μg iodine/g salt in rural Ethiopia.

It is unknown how well these experimental estimates correspond to population wide effects from introducing USI at scale in a low-income country due to lack of consistent and nationwide data on iodine deficiency, insufficient monitoring of the quality of iodized salt and potentially inequitable distribution (Gorstein, Bagriansky, Pearce, Kupka, & Zimmermann, 2020; Gumpricht et al., 2021). This study seeks to inform this knowledge gap.

3. USI in India

On 27 May 2005, the Government of India announced a national ban on the sale and storage of non-iodized salt for direct human consumption. The mandate came into effect on 17 May 2006 and stipulated the minimum iodine content of salt at the level of consumption to be 15 μg/g salt. Food inspectors in each state are responsible for monitoring the implementation of the ban, which includes testing of salt samples from producers, traders and shopkeepers. If the samples are found to be inadequately iodized at the retail level, all responsible persons will be fined and could be subject to imprisonment (Kapil, Dutt Sharma, Singh, Dwivedi, & Kaur, 2005; Vir, 2011).

Even though most states had state level bans prior to USI, they were not effective due to the absence of a ban in Gujarat, a state which produces around 80% of all salt in India (Pandav et al., 2003). The salt market in Gujarat comprises mostly of medium and small producers and traders for whom salt iodization is costly due to narrow profit margins (Vir, 2003). Before USI, non-iodized salt continued to be exported from Gujarat to the rest of India as it was difficult for intermediate suppliers and consumers to distinguish iodized from non-iodized salt. Wholesalers often purchase non-iodized salt in bulk and repackage it. Non-, or inadequately iodized salt was sold in packages with similar design, brands and logos to those of iodized salt, but at a lower price. The salt was often falsely labeled as adequately iodized (Vir, 2003). Additionally, state-level bans were weakly enforced due to the prioritization of other public health policies (Sankar, Moorthy, Pandav, Tiwari, & Karmarkar, 2006).[4]

A further barrier to the uptake of iodized salt prior to nationwide USI was a lack of information. Even though the majority of the Indian population are aware of iodized salt, only a quarter of individuals have knowledge about it (Kumar et al., 2013). Few know about other ill-effects of iodine deficiency than goiter. 17.1% know about mental retardation as an outcome and the percentage is likely to be lower among rural households. The "Smiling

[2] The human body cannot store iodine but it can store thyroid hormones which can meet the body's requirements for up to 3 months (Ahad & Ganie, 2010).

[3] Friedhoff, Miller, Armour, Schweitzer, and Mohan (2000) find that severe prenatal iodine deficiency has a larger impact on female learning than male rats. Nonetheless, it is questionable how well these results translate to humans with mild iodine deficiency. Murcia et al. (2011) study the correlation between a diet low in iodine, proxied by self-reported fish consumption and supplement intake, among pregnant mothers and infant neurodevelopment. The authors report gender differences in cognitive outcomes but the study does not address the multiple threats to identification.

[4] For example, despite Bihar having implemented a ban on non-iodized salt prior to 2006, enforcement was practically non-existent. An iodine deficiency disorder control task force was set up in 1988 but has not been functioning due to the crowding out of investment into public health policies such as Polio eradication and vitamin A campaigns (Sankar et al., 2006).

Sun" logo, used to mark that the salt is adequately iodized, is known to only 4% of respondents and the printing of the iodine content on packets is known to 15% (Kumar et al., 2013).[5]

It should be noted that a short-lived federal ban was in place in 1998–2000. It was quickly abolished as the mandate appeared to force the population to pay higher prices for salt. Grievances about unfair colonial taxes and monopolies on salt has made salt policies a sensitive political topic in India (Pandav, 2005).[6] The implementation of the earlier policy coincided with factors reducing the supply of iodized salt.[7] Furthermore, it is difficult to assess the effect of this brief mandate due to the absence of data on iodized salt consumption before 1998 (Pandav, 2013).

Advocacy for the re-introduction of USI among public health authorities and NGOs resulted in USI being enacted in 2006 (Pandav et al., 2003; Vir, 2003). I evaluate the impact of being exposed to mandatory USI for children in utero after 2006, compared to children who were in early life during the absence of the policy after 2001.[8] The lack of information about iodized salt and USI among consumers and distributors prior to 2006 suggests that selection in the uptake of iodized salt, or the brief previous USI, do not pose significant threats to the evaluation of the current USI legislation in rural India.

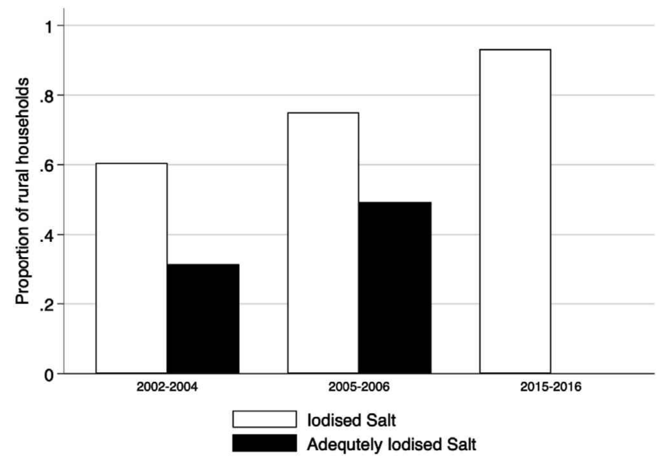

Fig. 1. Nationwide consumption of iodized salt over time. (The figure depicts the trends in the proportion of rural households consuming iodized and adequately iodized salt in India using the following data; 1998–2000 National Family Health Survey II, 2002–2004 District Level Health Survey II, 2005–2006 National Family Health Survey III and the 2015–2016 National Family Health Survey IV.)

4. Data and descriptive statistics

4.1. Iodized salt consumption

Fig. 1 shows the proportion of rural households in India consuming iodized and adequately iodized salt before and after USI. The graph uses data from the 2005–2006 and 2015–2016 Indian Demographic and Health Survey, also called the National Family Health Survey (NFHS) III and IV, and the 2002–2004 District Level Health Survey (DLHS) II.[9] These surveys include information on objectively measured iodine levels of salt at the household level. Survey enumerators measure the level of iodine in table salt using a rapid-test kit (IIPS, 2007).[10] All surveys report whether the salt contains some iodine or not, and earlier surveys provide additional information on whether the salt is adequately iodized. The salt is deemed adequately iodized if it contains at least 15 μg iodine/g salt, in line with government requirements. Around 60% of rural households consumed salt with some iodine in 2002–2004. This share increased to more than 70% around the time of the announcement and implementation of USI in 2005–2006 and has continued to rise since then. 92% of the rural population consumed iodized salt in 2015–2016. While data is not available for adequately iodized salt after 2006, we note a larger relative increase in the consumption of adequately iodized salt, compared to iodized salt, from 2002–2004 to around the time of USI implementation.

4.2. Historical goiter endemicity

Most iodine in soils is derived from the atmosphere, where in turn, it originates from the oceans which contain the highest concentration of iodide (Fuge, 2007). Therefore, coastal soils are likely to be richer in iodine compared to inland soils. In many parts of India, deficiency of iodine in the soil–water ecosystem is due to heavy rainfall, steep gradient and poor vegetation cover resulting in quick run-off and little time for the transfer of iodine. For instance, the soils in the Himalayan foothills are low in iodine due to glaciation during the last ice age, which stripped the soil of iodine (Fuge, 2007).

The best measure of inadequate local iodine availability is the prevalence of pre-fortification goiter due to heterogeneity in iodine availability in the soil accessible to humans and the lack of nationally representative data on the iodine content in soil and groundwater. While other micronutrient deficiencies are likely to decrease with rising caloric intake, the risk of iodine deficiency is locally persistent due to its geographical determinants. The "Himalayan goiter belt" is the world's largest and most intense goiter endemic area (Pandav & Kochupillai, 1982). Other areas, such as pockets of the Indian west coast also have a high prevalence of iodine deficiency due to heavy rainfalls, alluvial soils and less saline groundwaters (Smedley, 2004). Following Politi (2010a, 2010b), Feyrer et al. (2017) and Adhvaryu et al. (2020), I define naturally iodine deficient areas by the prevalence of goiter endemicity prior to the availability of iodine supplementation. Individuals who reside in previously endemic areas are more likely to benefit from USI in comparison to individuals living in always iodine sufficient locations.

I use information on goiter endemicity in 1915 across British India from McCarrison (1915). Sir McCarrisson, a British physician, compiled and mapped data on goiter incidence provided by admin-

[5] Vir (2011)[pp. 596] evaluates state programs aiming to increase iodized salt consumption and conclude that "..even if the public is made aware of the significance of iodized salt and convinced to consume only adequately iodized salt, the consumers are not in a position to distinguish adequately iodized salt from non-iodized or inadequately iodized salt due to the misleading practice for incorrect labeling regarding iodine content".

[6] Before 1923, the salt tax was contributing 1/3 of total revenue earned by the British Government in India (Saline Area Vitalization Enterprise Limited, 2005). Such grievances have remained in Indian politics and many dissenting voices, especially with roots in the independence movement were raised which caused the removal of the ban on 13 September 2000 (Pandav, 2005). Due to political pressure, the government quickly withdrew the policy with the motivation that "..matters of public health should be left to informed choice and not enforced." (Rah et al., 2015).

[7] The major salt producing state of Gujarat was hit by a cyclone in 1997 and later by an earthquake, which took years for restoration. Moreover, the de-licensing of the salt industry in 1996 made it more difficult for the Salt Department to regulate production (Pandav et al., 2003; Salt Commissioner's Organisation, 2004).

[8] I will not focus on the earlier policy of 1998–2000, due to lack of information on its efficacy and due to its very short time span. Children who were in utero during the prior attempt at USI, were still in a critical postnatal time period for brain development when it was abolished.

[9] I accessed the publicly available NFHS data through application to the DHS program. More information about the data and access is available in National Family Health Survey, India (2009). The DLHS was obtained after application at District Level Household & Facility (2013).

[10] The test kit consists of a solution which will change color depending on the level of iodine in the salt. The surveys report a categorical measure of the iodine content in salt; no iodine, some iodine and whether the salt has an adequate amount of iodine (IIPS, 2007).

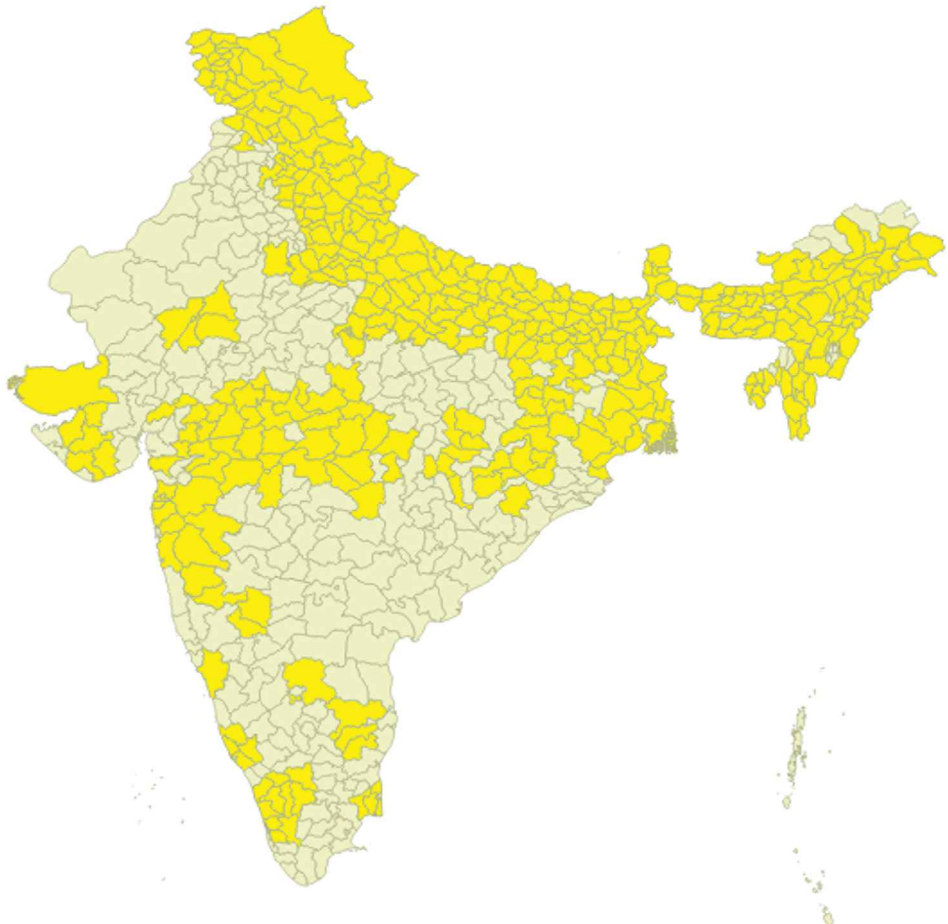

Fig. 2. Historical goiter endemicity by district. (This figure shows the location of historical goiter endemicity of Indian districts as of 2001. The bright yellow areas represent districts that contained at least one goiter endemic area in McCarrison (1915) and thus defined as pre-fortification goiter endemic. The light yellow districts are deemed as non-endemic.)

istrative medical officers and civil surgeons.[11] McCarrison (1915) depicts goiter endemic areas by dots. The original map is shown in Fig. 6 in Appendix A.1.1. For the analysis, a district from the 2001 Census is defined as historically endemic if it contained at least one goiter endemic location in 1915. Districts containing no dots are defined as non-endemic.[12] The map of historically goiter endemic districts is shown in Fig. 2. Dark yellow areas represent districts which are naturally at risk for iodine deficiency.

The data in McCarrison (1915) is prone to measurement error as it is unknown how the information was collected and how goiter endemicity was defined.[13] To assess its validity as a proxy for current risk for iodine deficiency, I inspect the relationship between the location of historical goiter endemicity and child goiter data collected during 1940–2001 for 263 districts.[14] Bivariate regressions show that a 10% or higher child goiter rate increases the probability of a district containing at least one historical endemic location by 25.1 percentage points, see Table A1 in Appendix A.1.1.[15] Additionally, goiter endemicity information from McCarrison (1915) predicts the prevalence of goiter and other thyroid illnesses per state in the 2005–2006 NFHS III, see Table A2 in Appendix A.1.1.[16] Goiter prevalence at the start of USI represents the risk of iodine deficiency before the policy as there can be a lag up to several years before iodine repletion reduces goiter (Zimmermann et al., 2003).

4.3. Cognitive test scores

ASER is used to measure the impact of USI in early life on cognitive test scores. ASER is a cross-sectional survey which tests around 500,000 children aged 5–16 in rural India each year in reading and mathematics. ASER is unique in that it includes both in- and out of school children as the children are tested at home. The survey is representative at the rural district level. For the analysis, I pool all surveys spanning 2007–2014 covering 587 districts.

The numeracy assessment consists of four levels of mastery: single-digit number recognition, double-digit number recognition,

[11] McCarrison (1915) writes: "Through the kindness of Administrative Medical Officers, and with the generous assistance of Civil Surgeons, I have been enabled to collect detailed information regarding the prevalence and distribution of goiter in almost every part of British India."

[12] The geographic information system software QGIS is used to digitize the location of the goiter endemic areas in Fig. 6 and spatially match them to districts from the 2001 Indian Census.

[13] McCarrison (1915) highlights the caveats with the map; "It is of course impossible, in a map of these dimensions to indicate every area with the accuracy of detail that is desirable. The map, therefore is to be regarded only as affording an approximately accurate indication of the general distribution of the disease over India."

[14] The data is described in Appendix A.1.1.

[15] Moreover, the spatial distribution of goiter in McCarrison (1915) appears to have understated the prevalence as more districts have been found to be endemic despite later public health efforts (Pandav, 2013). Therefore, using McCarrison (1915) to identify districts that are likely to benefit from iodized salt will at most underestimate the true effect of USI on human capital in rural India.

[16] A district level analysis is not possible as the 2005–2006 NFHS III does not provide district identifiers.

two-digit subtraction with carry over, and three digit by one digit division. Similarly, the literacy assessment tests four levels of skills: letter recognition, word recognition, reading comprehension of a short paragraph (a class 1 level text), and a short story (a class 2 level text). For both tests separately, the child is marked at the highest level they can do with scores ranging from 0 to 4: a score of 0 means that the child cannot do even the most basic level, a score of 4 means that he or she can do level 4 in the respective subject. The child's highest proficiency ranging 0–4 denotes his or her test score in numeracy and literacy, respectively.

I also generate age-standardized test scores to better account for variation in age. Moreover, investigating the impact on basic proficiency can reveal heterogeneous impacts of USI. I create a binary variable denoting basic numeracy taking value 1 if the child can recognize single-digit numbers or more, and 0 if the child cannot recognize single digit numbers. Similarly, a basic literacy dummy measures whether the child recognizes letters or not. The analytical sample is restricted to children aged 5–10 years as the skills tested in the survey reflect the expectations of lower primary school-aged children.

ASER includes limited information on household characteristics. The household reports the type of house the household resides in which proxies household wealth. "Pucca" denotes a house made of durable materials such as brick, stones or cement, "Kutcha" means a house made of less durable materials such as mud, reeds, or bamboo, and "Semi-Pucca" is something in between. Hence, "Pucca" is a proxy for relatively high economic status. Surveys from 2009 and onward contain village level information, such as the availability of a government primary school, Anganwadi center or a ration shop in the village and whether the village is connected to a pucca road. An Anganwadi center offers basic health, nutrition and schooling services to young children. A ration shop provides food from the public distribution system.

The ASER data is merged with information on whether the district of residence is historically goiter endemic or not. Summary statistics for cohorts born in 2002–2004 who were in early life prior to USI, across endemic and non-endemic districts with non-missing information on covariates, are presented in Table 1. Primary school-aged children in districts at risk for iodine deficiency score lower on almost all measures of cognitive test scores. The differences in numeracy appear to decrease slightly with levels of difficulty. Rates of school enrollment, drop out, and private school enrollment are similar across groups. Children residing in historically iodine deficient districts are more likely to take private tuition.

Summary statistics by gender reveal that girls' total numeracy score, as well as the age-standardized equivalent, is lower than for boys, see Table A3 in Appendix A.2. On the other hand, stark contrasts by gender are not apparent for the literacy score. We note somewhat larger differences by historical goiter endemicity for girls' test scores compared to boys'.

From Table 1 we observe that children in districts predisposed to iodine deficiency, on average have mothers with less schooling attainment, reside in housing made of less durable material, live in larger households and have worse access to village amenities, compared to children in always iodine sufficient districts. Given previous findings on the relationship between iodine deficiency, human capital and income in Politi (2010a, 2010b), Feyrer et al. (2017) and Adhvaryu et al. (2020), one cannot rule out that goiter endemic districts are disadvantaged due to long lasting iodine deficiency.

Trends in numeracy and literacy for children aged 5–10 by birth year and historical goiter endemicity are plotted in Fig. 3. Separate trends are shown for the raw scores, age-standardized scores and basic skills. We observe declining trends across all measures. The overall drop in test scores has been observed in previous studies (Chatterjee et al., 2018; Shah and Steinberg, 2019). It has been attributed to an average decline in the attendance rate and the nationwide implementation of the Right of Children to Free and Compulsory Education Act in 2009 (Shah and Steinberg 2019).[17]

Parallel trends are observed for children in early life in 2002–2005 prior to USI across districts with and without a predisposition to iodine deficiency. In line with the hypothesis, we observe diverging trends in test scores for cohorts born after USI in 2006. Parallel trends in literacy and schooling are also observed for endemic and non-endemic districts prior to the time period covered in Fig. 8 in the Appendix. Additionally, there are no diverging trends in household and village level characteristics by birth year and risk for iodine deficiency, see Fig. 9. A caveat is that we observe these characteristics at the time of the survey and not at the time of birth of the child. Nonetheless, the graphs reduce the concern of differential trends in determinants of human capital across groups, or selection, despite differences in baseline characteristics.

5. Empirical analysis

5.1. Effect of USI on thyroid related illnesses

First, I show that USI reduced thyroid disease to a larger extent in historically goiter endemic districts compared to non-endemic districts. The "First Stage" equation is estimated as follows;

$$\text{Thyroid Illness}_{ts} = \alpha_0 + \delta \text{USI}_t + \gamma \text{Endemic}_s + \theta(\text{USI}_t * \text{Endemic}_s) + \beta \text{Fish}_{ts} + \phi_s + \phi_t + \mu_{ts} \quad (1)$$

The outcome variable, Thyroid Illness, represents the change in the prevalence of goiter and other thyroid related disorders per state from the 2005–2006 to the 2015–2016 NFHS. Endemic designates the number of historically goiter endemic localities per area/state. For ease of interpretation, the outcome and the independent variable of interest are measured as deciles within their respective distributions. State and survey fixed effects are included and the standard errors are clustered at the state level. Controls are subsequently added for state averages of the frequency of fish consumption (never (0), occasionally (1), weekly (2) or daily (3)). Regression results presented in Table 2 point to that a decile increase in previously goiter endemic localities reduces the prevalence of thyroid disorders by half a decile, following USI. The parameter is robust to controlling for fish consumption, see column (2).

5.2. Preliminary analysis: Flexible treatment specification

Cohorts who were in early life during USI in previously goiter endemic districts, are more likely to have experienced an improvement in cognition compared to earlier cohorts in the same districts during no policy, relative to the changes across cohorts in iodine sufficient districts. I begin by estimating the flexible empirical specification presented in Eq. 2 which allows the data to show the relationship between year of birth and risk for iodine deficiency.

[17] Under this act, every child up to the age of 14 is guaranteed free and compulsory education, and no child can be held back or be expelled until grade 10. Moreover, teachers in India have not been able to change teaching according to the changed composition in school enrollment as teachers must cover the entire year's formal curriculum according to law. Using ASER data Shah and Steinberg (2019) report that the act is associated with an increased enrollment from 0.927 in 2004–2008 to 0.936 in 2011–2014 after the policy. The study also finds that both math and reading scores drop sharply a couple of years in both public and private schools. The authors conclude that the decrease in test scores could be attributed to overcrowding, potential change in the composition of students across public and private schools, changing pedagogical strategies, increased passing of students leading to decreased learning for pupils who are not prepared for upper level courses and negative peer effects.

Table 1
Descriptive statistics: Children in early life prior to USI in historically goiter endemic and non-endemic districts.

	Endemic		Non-endemic	
	Mean	SD	Mean	SD
Numeracy Score	1.81	1.18	1.91	1.14
Age standardized numeracy score	−0.09	1.02	−0.01	0.97
Basic Numeracy (Single-digit number recognition)	0.86	0.35	0.89	0.31
Double-digit number recognition	0.57	0.50	0.62	0.49
Subtraction	0.28	0.45	0.30	0.46
Division	0.10	0.30	0.10	0.30
Literacy Score	1.97	1.36	2.13	1.32
Age standardized literacy score	−0.07	1.04	0.04	0.99
Basic Literacy (Letter recognition)	0.84	0.36	0.89	0.32
Word recognition	0.57	0.49	0.63	0.48
Class 1 reading comprehension	0.36	0.48	0.39	0.49
Class 2 reading comprehension	0.20	0.40	0.22	0.41
Enrolled in school	0.99	0.10	0.99	0.07
Grade	2.92	1.55	3.09	1.52
Enrolled in Private School	0.28	0.45	0.28	0.45
Private Tuition	0.19	0.40	0.16	0.37
Dropped out	0.00	0.07	0.00	0.06
Age	7.98	1.50	8.03	1.47
Girl	0.47	0.50	0.47	0.50
Maternal education (years)	3.87	4.45	4.24	4.52
Kutcha House	0.40	0.49	0.32	0.46
Pucca House	0.28	0.45	0.38	0.49
Household size	6.79	3.24	6.23	2.94
Primary school in village	0.92	0.27	0.93	0.25
Anganwadi in village	0.90	0.30	0.95	0.21
Pucca road in village	0.71	0.45	0.82	0.38
Ration shop in village	0.68	0.46	0.73	0.44
Observations	346569		211567	

Note. This table reports the means and standard deviations for children who were in early life during the absence of nationwide USI, born in 2002–2004, in historically goiter endemic and non-endemic districts.

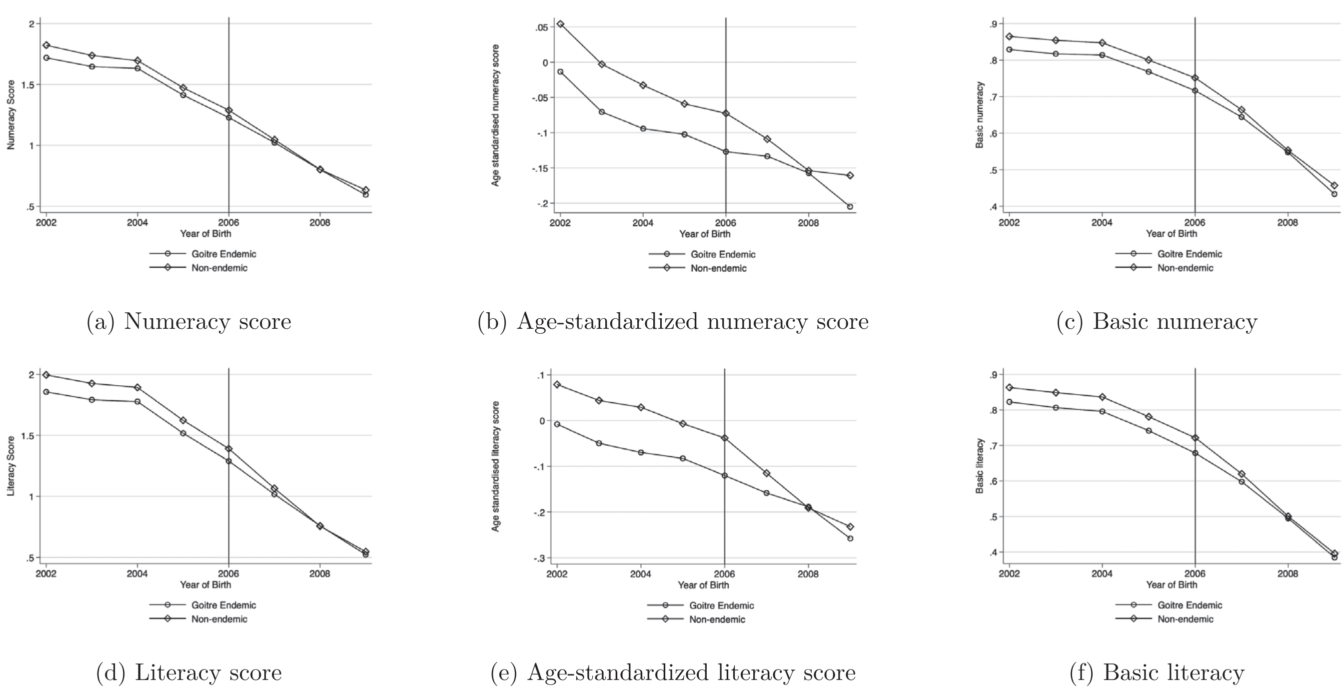

Fig. 3. Trends in cognitive test scores by birth year and goiter endemicity. (The figure shows trends in cognitive test scores by birth year and goiter endemicity using data from the Annual Status of Education Report.)

$$\text{Test Scores}_{idts} = \alpha_0 + \sum_{t \neq 2002} \delta_{dt}[yob * Endemic] + \beta X_{idt} + \phi_d + \phi_t + \phi_s + \phi_{s*t} + \mu_{idts} \quad (2)$$

Test Scores denote literacy and numeracy skills for child i, in district d, born in year t and tested in survey year s.[18] The omitted reference year is 2004, as this is the last cohort to not have been exposed to USI prior to age 2. *Endemic* is a binary variable which

Table 2
Effect of USI on the prevalence of thyroid related illnesses by historical goiter endemicity.

	(1) Thyroid disorder prevalence	(2) Thyroid disorder prevalence
USI * Historical goiter endemicity	−0.514*	−0.499*
	(0.257)	(0.268)
Survey	5.280***	5.224***
	(1.168)	(1.219)
Frequency of fish consumption		1.768
		(3.353)
Constant	4.167***	1.902
	(0.349)	(4.260)
Observations	48	48
R^2	0.445	0.454

Note. This table reports the regression results from Eq. 1. Data from the 2005–2006 NFHS IV and the 2015–2016 NHFS V is used. The outcome variable is the change in the percentile of state level average prevalence of self-reported thyroid related illnesses. Independent variables are: USI, which takes value 1 if the timing of the survey was 2015–2016 and 0 if it is 2005–2006, the decile of the distribution of the number of historical goiter endemic areas from McCarrison (1915) per area per state (km^2/10 000). A control variable for the average of households' frequency of eating fish/week per state is added in column 2. Robust standard errors are clustered on state and shown in parentheses. * $p < .10$, ** $p < .05$, *** $p < .01$.

takes value 1 if the child resides in a pre-fortification goiter endemic district, and 0 if the child resides in a non-endemic district.[19] The coefficient of interest, δ, captures the interaction effect of year of birth and goiter endemicity, in comparison to those born during the absence of the policy in 2004. I include district fixed effects, ϕ_d, and year of birth fixed effects ϕ_t. Interactions between birth years and survey years $\phi_{s*\,t}$, are added to control for changes in education for different years, and this also controls for the age of the child. Standard errors are clustered at the district level to account for within-district serial correlation.

Fig. 4 plots the coefficients on δ for the pooled sample. Overall, the graphs do not show any significant differences in test scores for cohorts born before the policy which suggests that the parallel trends assumption is not violated. It appears that the literacy score increased marginally for children exposed to USI in postnatal life, born in 2005. A more convincing relationship emerges for cohorts who were likely to be exposed to USI in utero. Children in previously iodine deficient districts, born in 2007 and after, experienced a rise in cognitive skills relative to children born at the same time in always iodine sufficient districts.

5.3. Main analysis: Effect of USI on cognitive test scores

Next, the impact of USI is evaluated using a traditional difference-in-differences framework. The econometric model is specified in Eq. 3.

$$\text{Human Capital}_{idts} = \alpha_0 + \delta \text{USI}_t + \gamma \text{Endemic}_d + \theta(\text{USI}_t * \text{Endemic}_d) + \beta X_{idts} + \phi_d + \phi_t + \phi_s + \phi \text{Trend}_d + \phi_{s*t} + \mu_{idts} \quad (3)$$

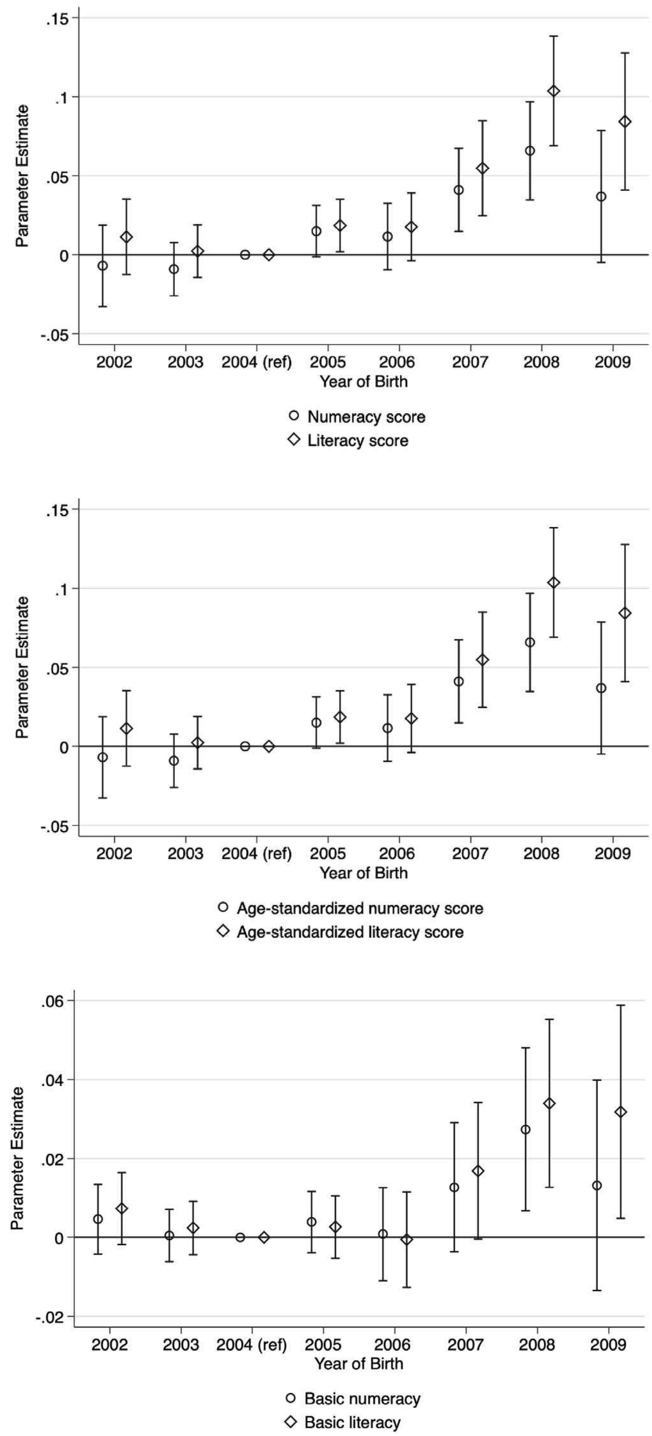

Fig. 4. The effect of USI on cognitive test scores: Flexible treatment specification. (This graph plots the coefficients on birth year interacted with district level goiter endemicity as specified in Eq. 2. Data from ASER merged with historical information on district level goiter endemicity is used for the analysis. The reference birth year is 2004. Fixed effects for district, year of birth, and survey year interacted with year of birth, are included. The y-axis shows the magnitude of the coefficients, the x-axis represents birth year and the lines through the plotted coefficients are confidence intervals.).

Human Capital denotes raw- and age-standardized test scores and basic attainment, as well as other educational outcomes, for child i, in district d, born in year t and tested in survey year s. USI is a binary variable taking value 1 if the child was born in 2007–2009 and thus benefited from USI in utero and throughout

[19] I assume that the district at the time of the survey is also the child's district of birth as migration rates are very low in rural India. Shah and Steinberg (2019) show that the inter-district rural migration rate for children aged 5–14. is 0.02 (all ages is 0.078) using Indian Census data from 2001.

postnatal life, and 0 if the child was born in 2002–2004 and therefore in early life during the absence of the policy. The control cohorts must not have been exposed to the policy from one year prior to birth up to age 2 as the first 1000 days (including fetal life) are critical for iodine intake and brain development (Stinca et al., 2017).[20] Endemic indicates the residence in a historically goiter endemic district. The difference-in-differences parameter of interest, θ, captures the effect of USI exposure during early life for children in naturally iodine deficient districts on cognitive test scores. The regressions are estimated for the pooled sample and for girls and boys separately.

The following covariates are included; district fixed effects, ϕ_d, year of birth fixed effects ϕ_t, survey year fixed effects ϕ_s and interactions between year of birth fixed effects and survey year ϕ_{s*t}. Controls for district level specific trends, ϕTrend_d, are included as education programs are administered at the district level (Department of Education, 1993). I further condition on; housing type (semi-pucca and pucca compared to the omitted category kutcha), years of maternal education and household size. The following village level covariates are added: whether the village has a government primary school, an Anganwadi center, a ration shop and is connected to a pucca road. ASER surveys from 2007 and 2008 do not contain information on village characteristics. To keep the estimation with and without covariates consistent, I restrict the analytical sample to observations for whom village covariates are available. μ_{idts} is the error term and the standard errors are clustered on districts.

The regression results are presented in Table 3. Panel A shows the effects of USI on the numeracy and literacy score, ranging from 0–4. No effects are found on numeracy or literacy scores for the pooled sample. Turning to the subsample of girls, we note a positive and statistically significant effect of 0.069 points increase in the literacy score, see column (8). No effects are found for boys. On the other hand, a positive effect is found on the age-standardized literacy score for the pooled sample, see column (4) in Panel B. The effect is driven by an increase of 6.1% of a standard deviation in girls' age-standardized literacy, see column (8) in Panel B.

In column (2), Panel C in Table 3, we observe that USI in early life improves the probability of recognizing single digit numbers or more, by 2.4 percentage points (2.8% of the mean). Exposure to USI increased the likelihood of mastering basic numeracy by 3.2 percentage points for girls (3.8% at their group mean), see column (6). The corresponding difference-in-differences coefficient for boys is 1.8 percentage points (2.1% at their group mean), see column (10). The gender differences are not statistically significant. The policy increased basic literacy attainment with 2.6 percentage points for the pooled sample, see Panel C, column (4). The effect is driven by an improvement by 3.7 percentage points for girls, see column (8), and corresponds to an increase by 4.4% in the likelihood of girls' mastering basic literacy. The coefficient fails to reach statistical significance for boys (see column (12)). The larger effects of iodine intake on literacy compared to numeracy, corroborate findings in Huda, Grantham-McGregor, Rahman, and Tomkins (1999) who argue that literacy reflects a long-term cumulative process of children's learning rather than current functioning.

The results hold when using the standardized number of historically goiter endemic areas per district in place of the binary measure for pre-fortification deficiency, see Table A4 in the Appendix. To account for any inter-district trade in agricultural products, I compute and standardize the number of historical goiter points per National Sample Survey (NSS) region and estimate a similar model to Eq. 3.[21] Atkin et al. (2013) proves that Indian agricultural markets consist of 77 segmented markets defined by NSS regions drawn along agro-climatic boundaries within states.[22] The findings are qualitatively similar to when using district boundaries, see Table A5 in the Appendix.

Exposure to USI did not impact school enrollment, see Panel A in Table 4. This is in line with Bleakley (2010) who shows that improved childhood health can raise the inframarginal return to education, i.e. the quality of education received, without necessarily raising the quantity of schooling due to the opportunity costs of schooling. Moreover, the lack of an effect on enrollment is not surprising as primary school enrollment has become near universal in India.

From Panel B in Table 4, we observe positive effects for grade progression across all subsamples. A larger effect is observed for boys' grade progression despite their smaller cognitive gains compared to girls. Exposure to USI also leads to a marginal reduction in the risk of dropping out of school for the pooled sample, see Panel C, column (4). Differential trends in private school enrollment or in paid tuition might pose a threat to the identification strategy as children in private schools have better test scores (Muralidharan & Kremer, 2009). From Table A6 in the Appendix, one notes that the policy is not associated with private school enrollment or tutoring. This strengthens our confidence in that the positive effects on learning outcomes are driven by improved cognition.

6. Heterogeneous effects

Blanket fortification policies could be at risk of not reaching key-populations. Therefore, I inspect whether there are heterogeneous effects of USI in early life on cognitive test scores by socio-economic status. Treatment is interacted with a binary variable taking value 1 if the child resides in a "Kutcha" house which is a proxy for poor households, and 0 if the child resides in "Semi-Pucca" or a "Pucca" house which identify non-poor and better off households. From Panel A and B in Table 5 we note that USI has a larger impact on literacy scores for the pooled sample and for boys from poor backgrounds. Additionally, poor children across all samples improved their basic literacy skills more than non-poor children. Heterogeneous treatment effects are also noted for basic numeracy for the pooled sample which is driven by positive effects on girls. Poorer children have a potentially higher propensity to benefit from the policy due to lower baseline test scores and nutrition status. Another possible explanation is that USI succeeded in disproportionately raising the consumption of iodized salt more for households of lower socio-economic status, compared to richer households.

The main results show that USI improved basic skills for the pooled sample but girls also improved their literacy score which takes more difficult levels of attainment into account. Adhvaryu et al. (2020), Deng and Lindeboom (2019), Field et al. (2009), Huang et al. (2020) and Politi (2010a) report that iodine supplementation only affects women's human capital or have stronger effects for women compared to men.[23] Cognitive skills in childhood are a product of cognitive endowment and parental inputs. Girls may

[20] The choice of control cohorts allows for a one year lag after the removal of the short lived USI policy in 2000.

[21] NSS fixed effects and NSS region specific time trends are controlled for and standard errors are clustered on NSS regions.

[22] India is dominated by smaller rural agricultural primary markets meeting local demand. Despite trade liberalization, internal trade remains low. Interstate tariffs, extensive trade regulations, and high transport costs constitute large barriers and affect rural households in particular (FAO, 2005; Atkin et al., 2013). External imports in agriculture are also low. In 2007/2008 agricultural imports were 4.32% of Indian GDP, see Chand, Raju, and Pandey (2010).

[23] Similar gender differences have been observed in papers studying the impact of other shocks in early life on schooling outcomes, see; Bobonis, Miguel, and Puri-Sharma (2006), Bleakley (2007), Maccini et al. (2009) and Maluccio et al. (2009).

Table 3
Effect of USI in early life on cognitive test scores.

	Pooled				Girls				Boys			
	(1) Numeracy	(2) Numeracy	(3) Literacy	(4) Literacy	(5) Numeracy	(6) Numeracy	(7) Literacy	(8) Literacy	(9) Numeracy	(10) Numeracy	(11) Literacy	(12) Literacy
Panel A: Test Score												
USI * Endemic	0.005	0.008	0.033	0.036	0.020	0.018	0.070**	0.069**	−0.007	−0.000	−0.001	0.006
	(0.020)	(0.019)	(0.023)	(0.023)	(0.025)	(0.024)	(0.031)	(0.030)	(0.025)	(0.024)	(0.028)	(0.028)
Controls		✓		✓		✓		✓		✓		✓
Observations	732215	732215	735688	735688	342505	342505	344108	344108	389710	389710	391580	391580
R^2	0.340	0.378	0.347	0.380	0.347	0.386	0.356	0.391	0.340	0.375	0.342	0.374
Panel B: Age-standardized test score												
USI * Endemic	0.011	0.014	0.032	0.035*	0.022	0.021	0.063**	0.061**	0.002	0.009	0.004	0.010
	(0.018)	(0.018)	(0.020)	(0.019)	(0.023)	(0.023)	(0.026)	(0.025)	(0.024)	(0.023)	(0.024)	(0.024)
Controls		✓		✓		✓		✓		✓		✓
Observations	732215	732215	735688	735688	342505	342505	344108	344108	389710	389710	391580	391580
R^2	0.134	0.182	0.108	0.153	0.156	0.205	0.126	0.174	0.120	0.167	0.099	0.141
Panel C: Basic Skills												
USI * Endemic	0.024***	0.024***	0.025***	0.026***	0.032***	0.032***	0.037***	0.037***	0.016	0.018*	0.015	0.016
	(0.009)	(0.009)	(0.009)	(0.009)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)
Controls		✓		✓		✓		✓		✓		✓
Observations	732215	732215	735688	735688	342505	342505	344108	344108	389710	389710	391580	391580
R^2	0.226	0.243	0.239	0.258	0.234	0.252	0.245	0.265	0.222	0.239	0.237	0.255

Note. This table reports the coefficients from Eq. 3 using the ASER data merged with historical information on district level goiter endemicity. The outcome variables are overall test scores, age-standardized test scores and basic skills in numeracy and literacy for children aged 5–10. The subsample of analysis and the type of skills are reported at the top of the table. The particular test score measure is reported in the first column from the left. The following fixed effects are included in all specifications; district, year of birth, survey year, survey year*year of birth and linear district trends. Columns 2, 4, 6, 8, 10 and 12 also include the following covariates; years of maternal education, household size, housing type, gender, primary school availability in village, anganwadi in village, village being connected to a pucca road and the presence of a ration shop in one's village of residence. Robust standard errors clustered on district are presented in parentheses. * $p < .10$, ** $p < .05$, *** $p < .01$.

Table 4
Effect of USI in early life on education outcomes.

	Pooled		Girls		Boys	
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Enrollment						
USI * Endemic	0.001	0.001	0.001	0.001	0.002	0.002
	(0.001)	(0.001)	(0.002)	(0.002)	(0.002)	(0.002)
Controls		✓		✓		✓
Observations	963470	963470	449904	449904	513566	513566
R^2	0.018	0.020	0.023	0.025	0.016	0.018
Panel B: Grade Progression						
USI * Endemic	0.075***	0.075***	0.055*	0.055*	0.093***	0.094***
	(0.022)	(0.022)	(0.028)	(0.028)	(0.027)	(0.027)
Controls		✓		✓		✓
Observations	696465	696465	326087	326087	370378	370378
R^2	0.560	0.560	0.573	0.573	0.551	0.551
Panel C: Drop out						
USI * Endemic	−0.001*	−0.002*	−0.002	−0.002	−0.001	−0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Controls		✓		✓		✓
Observations	963470	963470	449904	449904	513566	513566
R^2	0.009	0.010	0.011	0.013	0.009	0.010

This table reports the coefficients from Eq. 3 using the ASER data for children aged 5–10, merged with historical information on district level goiter endemicity. The outcome variables are reported on the left-hand side column. The subsample of analysis is reported at the top of the table. The following fixed effects are included in all specifications; district, year of birth, survey year, survey year*year of birth and linear district trends. Columns 2, 4 and 6 also include the following covariates; years of maternal education, household size, housing type, gender, primary school availability in village, anganwadi in village, village being connected to a pucca road and the presence of a ration shop in one's village of residence. Robust standard errors clustered on district are presented in parentheses. * $p < .10$, ** $p < .05$, *** $p < .01$.

have a higher capacity to benefit due to lower baseline levels of human capital attainment. Deng and Lindeboom (2019) find that gender preferences in China enhanced the female disadvantage in iodine deficient areas prior to USI and contributed to larger improvements in female learning outcomes after the policy.

This motivates the investigation of whether social gender institutions affect cognitive gains from USI in India as son preference is a well known fact in many parts of the country (Azam & Kingdon, 2013; Kishor, 1993; Mishra, Roy, & Retherford, 2004; Rosenzweig & Schultz, 1982). I use sex ratios of the number of girls to 1000 boys aged 0–6 years per district from the 2001 Census as a proxy for area level son preference.[24] Through prenatal sex selection and lower human capital investments in girls, the preference for sons have led to unbalanced sex ratios, higher female mortality rates and other adverse outcomes for girls and women (Anderson & Ray, 2012; Barcellos, Carvalho, & Lleras-Muney, 2014).

[24] Census data is available at https://censusindia.gov.in.

Table 5
Effect of USI in early life on cognitive test scores by socio-economic status

	Pooled				Girls				Boys			
	(1) Numeracy	(2) Numeracy	(3) Literacy	(4) Literacy	(5) Numeracy	(6) Numeracy	(7) Literacy	(8) Literacy	(9) Numeracy	(10) Numeracy	(11) Literacy	(12) Literacy
Panel A: Test Score												
USI * Endemic	−0.004	−0.005	0.017	0.016	0.011	0.006	0.059*	0.052*	−0.015	−0.012	−0.020	−0.017
	(0.020)	(0.020)	(0.023)	(0.023)	(0.025)	(0.024)	(0.030)	(0.030)	(0.025)	(0.025)	(0.029)	(0.029)
Kutcha House	−0.282***	−0.263***	−0.325***	−0.296***	−0.297***	−0.276***	−0.342***	−0.315***	−0.270***	−0.252***	−0.310***	−0.280***
	(0.012)	(0.011)	(0.014)	(0.013)	(0.014)	(0.013)	(0.016)	(0.015)	(0.013)	(0.012)	(0.015)	(0.015)
USI * Kutcha House	0.062***	0.077***	0.073***	0.089***	0.084***	0.097***	0.097***	0.111***	0.045***	0.061***	0.055***	0.072***
	(0.013)	(0.013)	(0.015)	(0.015)	(0.017)	(0.017)	(0.020)	(0.020)	(0.017)	(0.016)	(0.019)	(0.019)
Endemic * Kutcha House	−0.003	−0.013	−0.002	−0.014	0.017	0.005	0.016	0.003	−0.020	−0.030**	−0.018	−0.028
	(0.014)	(0.013)	(0.017)	(0.015)	(0.016)	(0.015)	(0.019)	(0.018)	(0.016)	(0.015)	(0.018)	(0.017)
USI * Endemic * Kutcha House	0.006	0.015	0.022	0.031*	−0.001	0.009	0.004	0.016	0.010	0.018	0.036	0.044*
	(0.016)	(0.016)	(0.019)	(0.018)	(0.021)	(0.020)	(0.024)	(0.024)	(0.020)	(0.020)	(0.023)	(0.023)
Controls		✓		✓		✓		✓		✓		✓
Observations	732215	732215	735688	735688	342505	342505	344108	344108	389710	389710	391580	391580
R^2	0.349	0.378	0.355	0.380	0.356	0.386	0.365	0.392	0.349	0.375	0.351	0.374
Panel B: Age-standardized test score												
USI * Endemic	0.005	0.004	0.020	0.019	0.015	0.010	0.054**	0.048*	−0.003	−0.000	−0.010	−0.008
	(0.019)	(0.019)	(0.020)	(0.020)	(0.023)	(0.023)	(0.026)	(0.026)	(0.024)	(0.024)	(0.025)	(0.025)
Kutcha House	−0.259***	−0.240***	−0.267***	−0.243***	−0.271***	−0.251***	−0.281***	−0.258***	−0.248***	−0.230***	−0.256***	−0.231***
	(0.011)	(0.011)	(0.011)	(0.011)	(0.013)	(0.013)	(0.013)	(0.013)	(0.012)	(0.012)	(0.012)	(0.012)
USI * Kutcha House	0.024*	0.038***	0.024*	0.038***	0.044***	0.057***	0.043**	0.056***	0.008	0.023	0.010	0.024
	(0.013)	(0.013)	(0.014)	(0.013)	(0.017)	(0.017)	(0.018)	(0.018)	(0.017)	(0.016)	(0.017)	(0.017)
Endemic * Kutcha House	−0.005	−0.015	−0.004	−0.014	0.014	0.002	0.011	−0.001	−0.021	−0.031**	−0.017	−0.025*
	(0.013)	(0.012)	(0.014)	(0.013)	(0.015)	(0.014)	(0.016)	(0.015)	(0.015)	(0.014)	(0.015)	(0.014)
USI * Endemic * Kutcha House	0.009	0.017	0.025	0.033**	0.005	0.014	0.011	0.021	0.011	0.018	0.035*	0.041**
	(0.016)	(0.016)	(0.017)	(0.016)	(0.021)	(0.020)	(0.022)	(0.021)	(0.021)	(0.020)	(0.021)	(0.020)
Controls		✓		✓		✓		✓		✓		✓
Observations	732215	732215	735688	735688	342505	342505	344108	344108	389710	389710	391580	391580
R^2	0.145	0.182	0.120	0.154	0.167	0.205	0.138	0.174	0.132	0.167	0.110	0.141
Panel C: Basic Skills												
USI * Endemic	0.023***	0.023***	0.021**	0.021**	0.029***	0.028***	0.033***	0.031***	0.018*	0.019*	0.011	0.012
	(0.009)	(0.009)	(0.009)	(0.009)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)
Kutcha House	−0.051***	−0.044***	−0.053***	−0.046***	−0.053***	−0.047***	−0.055***	−0.048***	−0.048***	−0.042***	−0.051***	−0.044***
	(0.003)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
USI * Kutcha House	−0.063***	−0.060***	−0.064***	−0.061***	−0.057***	−0.054***	−0.058***	−0.055***	−0.067***	−0.064***	−0.069***	−0.066***
	(0.006)	(0.006)	(0.006)	(0.006)	(0.008)	(0.008)	(0.009)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)
Endemic * Kutcha House	−0.008*	−0.010**	−0.011**	−0.013***	−0.007	−0.009*	−0.010*	−0.012**	−0.009**	−0.011**	−0.012**	−0.014***
	(0.004)	(0.004)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
USI * Endemic * Kutcha House	0.016**	0.018**	0.025***	0.027***	0.020*	0.022**	0.025**	0.027***	0.011	0.013	0.024**	0.026***
	(0.008)	(0.008)	(0.008)	(0.008)	(0.010)	(0.010)	(0.011)	(0.011)	(0.010)	(0.010)	(0.010)	(0.009)
Controls		✓		✓		✓		✓		✓		✓
Observations	732215	732215	735688	735688	342505	342505	344108	344108	389710	389710	391580	391580
R^2	0.231	0.244	0.244	0.258	0.239	0.252	0.251	0.265	0.228	0.240	0.242	0.255

Note. This table reports the coefficients from Eq. 3 in addition with an interaction of the treatment of interest and housing type. ASER data merged with historical information on district level goiter endemicity is used for the analysis. The outcome variables are overall test scores, age-standardized test scores and basic skills in numeracy and literacy for children aged 5–10. The subsample of analysis and the type of skills are reported at the top of the table. The particular test score measure is reported in the first column from the left. The reference housing type category is "kutcha". The following fixed effects are included in all specifications; district, year of birth, survey year, survey year*year of birth and linear district trends. Columns 2, 4, 6, 8, 10 and 12 also include the following covariates; years of maternal education, household size, gender, primary school availability in village, anganwadi in village, village being connected to a pucca road and the presence of a ration shop in one's village of residence. Robust standard errors clustered on district are presented in parentheses. * $p < .10$, ** $p < .05$, *** $p < .01$.

The difference-in-differences parameter in Eq. 3 is interacted with a binary variable taking value 1 if the district of residence has a sex ratio above the national median, and 0 otherwise. A larger sex ratio indicates that a district is more balanced with regards to gender and suffers less from son bias. The estimates do not lend support to that the treatment effect varies with respect to district sex ratios, see Table A7.[25]

7. Robustness

7.1. Validity tests

To rule out that treatment is driven by latent trends in the outcome variables, including mean reversion or concurrent policies, regression results are presented where interactions between birth year and various district level characteristics at baseline are controlled for.

India's National Rural Employment Guarantee Scheme (NREGS), which guarantees 100 days of work, has been shown to affect children's human capital. For example, Shah and Steinberg (2021) show that exposure to workfare decreases enrollment by 1–3.5

[25] The conclusions hold when using 1980–1999 district-level sex ratio at last birth constructed from the 2002–2004 DHLS. Results are available upon request.

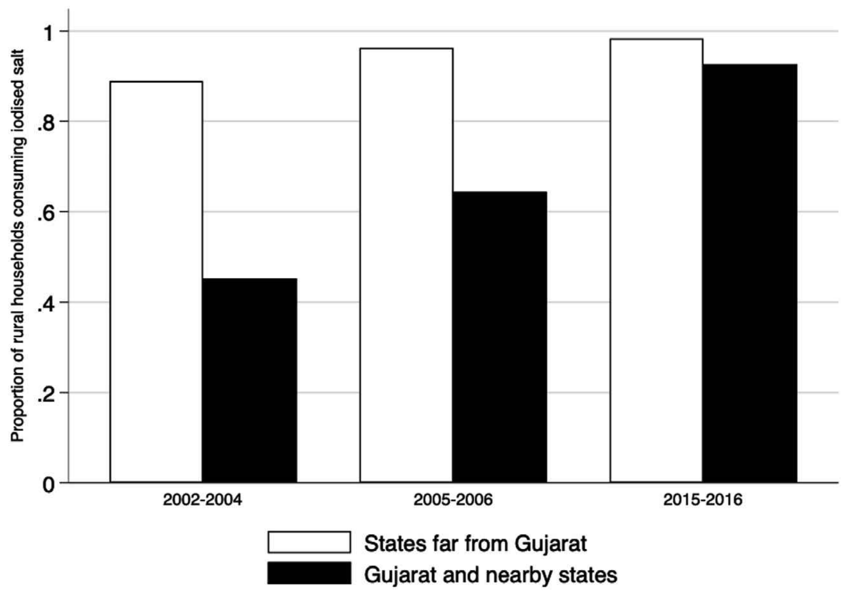

Fig. 5. Consumption of iodized salt across time and states near and far from Gujarat. (The figure depicts trends in the proportion of rural households who consume iodized and non-iodized salt in; Gujarat and states near Gujarat, compared to the north eastern states of India. The following data is used; The 2002–2004 DLHS II, the 2005–2006 NFHS III and the 2015–2016 NFHS IV.)

percentage points. The program was introduced in three phases throughout rural India between early 2006 and 2008. The poorest districts got access to the program first which makes the selection into the early phase of NREGS a good indicator for overall district level economic development. Therefore, I interact a dummy variable taking value 1 if the district was selected for the early phase of NREGS, compared to the later two phases, with year of birth.[26]

In separate regressions, I also interact cohort with the following set of district characteristics; the percentage of population who belong to a Scheduled Caste, percentage of population who belong to a Scheduled Tribe, female literacy and the gross enrollment ratio in primary school. Scheduled Castes and Scheduled Tribes are stigmatized and marginalized and eligible for affirmative action (Shah and Steinberg, 2021). I control for the female literacy rate as a baseline measure of gender-specific human capital and primary school enrollment due to its potential relation to the impact of schooling policies such as the Right to Education Act. Demographic and literacy information is derived from the 2001 Indian Census and enrollment information is retrieved from the 2004 District Information System of Education (DISE).[27]

Controlling for either the early phase of NREGS implementation or the set of Census and enrollment covariates interacted with year of birth, yields qualitatively similar estimates to the main regressions, see Table A8 in the Appendix.[28]

Another potential threat to internal validity is the rollout of the National Rural Health Mission. The program was implemented in 2005 in deprived rural areas and has decentralized and improved the quality of the health delivery system (Husain, 2011). I estimate placebo regressions using the econometric strategy set out in Eq. 3. Data on health investments for the last and second to last born child to surveyed women in the DLHS II and III is used for the analysis. The outcome variables are; the probability of receiving BCG and measles vaccinations, vitamin A supplementation and having diarrhea two weeks prior to the survey. Diarrhea incidence is a proxy for the general health and sanitation environment. All estimates but one are statistically insignificant, see Table A9. The probability of receiving vaccination against BCG is 5.7 percentage points lower for children exposed to USI in early life in previously endemic districts. Thus, these findings rule out that improved health care services and health in early life explain the observed improvements in learning outcomes.

7.2. State differences in salt production and transportation

I exploit an additional source of exogenous variation in the propensity to benefit from the policy as a further robustness check. Gujarat produces the majority of all salt in India and while most states had local bans on non-iodized salt prior to nationwide USI, there was no legislation in Gujarat which made non-iodized salt available across the country. Iodized salt consumption was therefore particularly low in Gujarat. Iodized salt coverage was also lower in states near Gujarat compared to states further away. This was due to differences in the monitoring of salt which in turn depends on the mode of transport of salt across states. Salt transported by rail has always been subject to obligatory controls, monitoring and registration of the producer. Road transportation was not monitored which created little incentive for producers and distributors to adequately iodize salt (Vir, 2011, p. 586).

The distance from Gujarat to the importing state determines the choice of transport. Road transportation is more cost-effective for distances up to 500 km which includes the states of Rajasthan, Uttar Pradesh, Madhya Pradesh and Maharahstra (Vir, 2011, p. 586). Rail transportation is cost-effective for longer distances and therefore the north eastern states; Sikkim, Mizoram, Meghalaya, Nagaland, Tripura, Arunachal Pradesh, Manipur, Assam and West Bengal import most of their salt by rail. These states also use a nominee system which consists of appointed traders who procure salt (Vir, 2011, p. 586).[29] Graphing iodized salt consumption between 2002–2004 and 2015–2016 in Fig. 5 shows an increase from 45% to 93% in Gujarat and nearby states. States further away

[26] Information on NREGS rollout is available at https://nrega.nic.in/MNREGA_Dist.pdf.

[27] DISE census is publicly available for download at http://udise.in/. DISE data for 2004 includes the 2001 Census information used for the robustness analysis.

[28] The sample is reduced as some districts included in the later ASER waves emerged after the 2001 Census. Moreover, the state of Manipur and some other districts were not included in DISE.

[29] This system is biased in favor of large and registered salt producers who were more likely to produce adequately iodized salt and have their salt undergo inspections (Vir, 2011, p. 586).

from Gujarat which rely on rail transportation experienced a smaller increase, from 89% to 98%.

I use the distance to Gujarat as an additional source of variation and estimate a triple difference-in-differences by interacting the difference-in-differences parameter in Eq. 3 with a dummy variable taking value 1 if the child resides in a state with a low baseline of iodized salt (Gujarat or a state within 500 km of Gujarat), and 0 if the child lives in a high baseline state (a north eastern state with a nominee system). Standardized literacy scores for girls in states which saw a larger increase in iodized salt consumption improved by 8.1% of a standard deviation more compared to girls in states with a smaller increase in iodized salt coverage, see column (8) in Panel B in Table 6. Children in, and near, Gujarat also raised their basic numeracy skills more across all sub-samples, see Panel C. We observe a 8.1 and 7.6 percentage points relative increase in the likelihood of mastering basic numeracy and literacy, respectively.

7.3. Instrumental variable analysis

The indicator for historical goiter endemicity might suffer from measurement error due to limited information about the data collection in McCarrison (1915). Therefore, I check the robustness of

Table 6
Effect of USI in early life on cognitive test scores by proximity to Gujarat.

	Pooled				Girls				Boys			
	(1) Numeracy	(2) Numeracy	(3) Literacy	(4) Literacy	(5) Numeracy	(6) Numeracy	(7) Literacy	(8) Literacy	(9) Numeracy	(10) Numeracy	(11) Literacy	(12) Literacy
Panel A: Test Score												
USI * Endemic	0.047	0.031	0.073	0.060	0.060	0.058	0.106	0.111	0.029	0.001	0.035	0.006
	(0.080)	(0.079)	(0.091)	(0.091)	(0.099)	(0.098)	(0.097)	(0.098)	(0.085)	(0.089)	(0.106)	(0.106)
USI * in/near Gujarat	0.041	0.022	0.062	0.046	0.071	0.066	0.062	0.065	0.004	−0.025	0.051	0.019
	(0.078)	(0.077)	(0.089)	(0.089)	(0.097)	(0.096)	(0.097)	(0.098)	(0.084)	(0.088)	(0.104)	(0.104)
USI * Endemic * in/near Gujarat	−0.062	−0.045	−0.026	−0.011	−0.059	−0.060	−0.018	−0.026	−0.057	−0.024	−0.022	0.012
	(0.086)	(0.084)	(0.099)	(0.098)	(0.106)	(0.105)	(0.109)	(0.110)	(0.094)	(0.097)	(0.116)	(0.115)
Controls		✓		✓		✓		✓		✓		✓
Observations	409663	409663	411367	411367	189858	189858	190638	190638	219805	219805	220729	220729
R^2	0.323	0.363	0.329	0.367	0.326	0.367	0.334	0.374	0.326	0.364	0.329	0.364
Panel B: Age-standardized test score												
USI * Endemic	0.038	0.023	0.056	0.045	0.050	0.049	0.082	−0.011	0.022	−0.005	0.025	−0.000
	(0.078)	(0.077)	(0.078)	(0.078)	(0.098)	(0.097)	(0.082)	(0.037)	(0.083)	(0.086)	(0.094)	(0.093)
USI * in/near Gujarat	0.011	−0.006	0.024	0.010	0.038	0.034	0.018	−0.083**	−0.021	−0.049	0.019	−0.008
	(0.075)	(0.074)	(0.075)	(0.075)	(0.095)	(0.094)	(0.081)	(0.037)	(0.081)	(0.084)	(0.091)	(0.090)
USI * Endemic * in/near Gujarat	−0.032	−0.016	−0.002	0.010	−0.032	−0.033	0.006	0.081**	−0.025	0.007	−0.000	0.029
	(0.083)	(0.082)	(0.084)	(0.084)	(0.104)	(0.103)	(0.092)	(0.041)	(0.091)	(0.093)	(0.101)	(0.100)
Controls		✓		✓		✓		✓		✓		✓
Observations	409663	409663	411367	411367	189858	189858	190638	189858	219805	219805	220729	220729
R^2	0.137	0.188	0.105	0.155	0.161	0.211	0.121	0.255	0.122	0.171	0.097	0.144
Panel C: Basic Skills												
USI * Endemic	−0.022	−0.026	−0.027	−0.030*	−0.011	−0.011	−0.032*	−0.031	−0.032	−0.039	−0.022	−0.029
	(0.029)	(0.028)	(0.018)	(0.017)	(0.037)	(0.037)	(0.018)	(0.019)	(0.029)	(0.030)	(0.024)	(0.024)
USI * in/near Gujarat	−0.082***	−0.086***	−0.097***	−0.101***	−0.082**	−0.083**	−0.116***	−0.116***	−0.082***	−0.090***	−0.082***	−0.089***
	(0.028)	(0.027)	(0.016)	(0.016)	(0.037)	(0.037)	(0.017)	(0.018)	(0.028)	(0.029)	(0.023)	(0.023)
USI * Endemic * in/near Gujarat	0.077**	0.081**	0.073***	0.076***	0.081**	0.081**	0.096***	0.094***	0.075**	0.083**	0.053*	0.061**
	(0.032)	(0.032)	(0.023)	(0.022)	(0.041)	(0.041)	(0.025)	(0.025)	(0.034)	(0.034)	(0.029)	(0.029)
Controls		✓		✓		✓		✓		✓		✓
Observations	409663	409663	411367	411367	189858	189858	190638	190638	219805	219805	220729	220729
R^2	0.229	0.249	0.238	0.259	0.236	0.255	0.243	0.265	0.227	0.246	0.237	0.257

Note. This table reports the coefficients from Eq. 3 using the ASER data merged with historical information on district level goiter endemicity. The analysis is restricted to states with predominantly rail or road transportation of salt. The outcome variables are overall test scores, age-standardized test scores and basic skills in numeracy and literacy for children aged 5–10. The subsample of analysis and the type of skills are reported at the top of the table. The particular test score measure is reported in the first column from the left. The following fixed effects are included in all specifications; district, year of birth, survey year, survey year*year of birth and linear district trends. Columns 2, 4, 6, 8, 10 and 12 also include the following covariates; years of maternal education, household size, housing type, gender, primary school availability in village, anganwadi in village, village being connected to a pucca road and the presence of a ration shop in one's village of residence. Robust standard errors clustered on district are presented in parentheses. * $p < .10$, ** $p < .05$, *** $p < .01$.

Table 7
TSLS: Effect of USI in early life on test scores.

	Pooled		Girls		Boys	
	(1) Numeracy	(2) Literacy	(3) Numeracy	(4) Literacy	(5) Numeracy	(6) Literacy
Panel A: Test Score						
USI * Endemic	0.065	0.148**	0.111	0.266***	0.025	0.035
	(0.059)	(0.065)	(0.072)	(0.087)	(0.071)	(0.074)
Hansen J statistic (Overidentification test)	0.929	4.003	0.042	2.398	1.997	2.467
Hansen J statistic χ^2 p-value	0.6285	0.1351	0.9790	0.3016	0.3685	0.2913
Panel B: Age-standardized test score						
USI * Endemic	0.094*	0.141***	0.129*	0.232***	0.062	0.054
	(0.055)	(0.055)	(0.068)	(0.073)	(0.067)	(0.064)
Hansen J statistic (Overidentification test)	1.219	2.878	0.138	1.582	2.112	2.265
Hansen J statistic χ^2 p-value	0.5435	0.2372	0.9332	0.4535	0.3478	0.3222
Panel C: Basic Skills						
USI * Endemic	0.097***	0.131***	0.089***	0.127***	0.103***	0.133***
	(0.025)	(0.026)	(0.027)	(0.029)	(0.030)	(0.031)
Hansen J statistic (Overidentification test)	0.814	0.289	0.078	0.019	2.133	0.848
Hansen J statistic χ^2 p-value	0.6658	0.8655	0.9615	0.9905	0.3441	0.6543
Effective F statistic Olea and Pflueger (2013)	35.898	35.968	35.869	35.928	35.715	35.797
Observations	696915	700109	325878	327345	371037	372764

Note. This table reports the coefficients from Eq. 3 after instrumenting for goiter endemicity with distance to coast (100 km), altitude (km), average rainfall (1000 mm) (all interacted with the post-treatment indicator "USI"). Data from ASER is merged with historical information on district level goiter endemicity along with information on elevation, average rainfall and distance to coast per district. The outcome variables are overall test scores, age-standardized test scores and basic skills in numeracy and literacy for children aged 5–10. The subsample of analysis and the type of skills are reported at the top of the table. The particular test score measure is reported in the first column from the left. The following covariates are included in all specifications; district, year of birth, survey year, survey year*year of birth, linear district trends, years of maternal education, household size, housing type, gender, primary school availability in village, anganwadi in village, village being connected to a pucca road and the presence of a ration shop in one's village of residence. Robust standard errors clustered on district are presented in parentheses. * $p < .10$, ** $p < .05$, *** $p < .01$.
The robust critical value to reject the null hypothesis of 5% potential bias due to weak instruments at the 5% significance level for the Effective F statistic is 25.783.

the main results by instrumenting goiter endemicity with maximum elevation per district, distance from the district centroid to the coast and average district rainfall during 1951–2001.[30] Heavy rainfall and hilly topography encourages soil erosion and leaching which leads to iodine deficient soils (Brady & Weil, 1996, pp. 48–49). Furthermore, as iodine is mainly derived from the marine environment, the proximity to the coast determines the availability of iodine in the soil and groundwater (Fuge, 2007). While altitude, long-run precipitation and proximity to the coast may affect economic and human development in the long-run, these factors are plausibly exogenous to the timing of USI in conjunction with geography, in particular after conditioning on covariates such as district specific trends. The representative first stage, for the pooled sample accounting for the full set of controls, is presented in Table A10 in the Appendix. The coefficients on distance to the coast (100 km), maximum altitude (km), average rainfall (1000 mm) (all interacted with the post-treatment indicator "USI") point to an overall strong relationship between these variables and baseline goiter endemicity.

The TSLS results are presented in Table 7. The χ^2 p-values for the overidentification test using the Hansen J Statistic reported at the bottom of each panel indicate a failure to reject the hypothesis that the variables are jointly valid instruments. I assess the strength of the instruments using the robust effective F statistic by Olea and Pflueger (2013) which allows for errors that are not homoskedastic and serially uncorrelated and is recommended by Andrews, Stock, and Sun (2019) in over-identified settings with a single endogenous regressor in the presence of potentially heteroskedastic, serially correlated, or clustered model errors. This statistic tests the null hypothesis that the Nagar bias exceeds a fraction of a "worst-case" bias (Pflueger & Wang, 2015). All effective F statistics, ranging from 35.715 to 35.968, exceed the critical value of 25.781 for 5% of the "worst-case" bias with 5% significance level which suggests a rejection of the null hypothesis of weak instruments.

The IV results show that USI in early life increased literacy scores by 0.148 points and age-standardized literacy scores by 14.1% of a standard deviation for the pooled sample. The TSLS coefficients confirm that the overall effect stems from a rise in learning outcomes for girls for whom literacy scores increased by 0.266 points and by 23.2% of the age-standardized literacy score. Instrumenting for baseline risk of iodine deficiency reveals a consistent positive effect on basic skills for both genders. Girls who benefited from the policy during early life are 8.9 and 12.7 percentage points more likely to master basic literacy and numeracy, respectively. The corresponding increases are 10.3 and 13.3 percentage points for boys. The IV results suggest that the measurement error in the historical goiter dataset underestimates the true effect of USI on test scores when using OLS.

8. Conclusion

This study estimates the causal impact of USI on cognitive test scores in rural India. I use a difference-in-differences strategy comparing cohorts who were exposed to the policy in early life to earlier cohorts, across districts with and without a geographical predisposition to iodine deficiency. Data on both in and out of school children from the ASER is used for the analysis along with information on historical goiter endemicity identifying the propensity to benefit from added iodine.

Exposure to USI improves literacy scores by 6.1% of a standard deviation for girls. While no effects are found for boys' overall test scores, basic skills and grade progression improved for the pooled sample. The results pass several robustness tests, such as using an event-study framework, exploiting additional exogenous variation in baseline access to iodized salt in a triple difference-in-

[30] The elevation data comes from the Shuttle Radar Topography Mission from FAO Harmonized World Soil Database v 1.2. which is publicly available at http://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/harmonized-world-soil-database-v12/en/. The rainfall data is from the Ministry of Earth Sciences accessed through Open Government Data Platform India at https://data.gov.in.

differences strategy, and instrumenting for the risk of iodine deficiency with geographical predictors.

This paper provides robust evidence on the cognitive returns to USI in a developing country. While recent findings by Deng and Lindeboom (2019) and Huang et al. (2020) show that USI increased school enrollment and test scores for girls in China, the Chinese program is unique due to heavy state regulation and high baseline levels of iodized salt consumption. The effects from the Indian USI can be extrapolated to other developing countries as weak institutions and regulations, a majority of small-scale salt producers, high levels of general malnutrition and lack of awareness, are common barriers to successful USI across many low- and middle-income countries (Bishai & Nalubola, 2002).

Additionally, this study shows the mechanism by which historical salt iodization has been observed to improve long-run human capital outcomes in Adhvaryu et al. (2020) and Politi (2010a, 2010b) by directly investigating the effects on cognition in childhood for a representative sample. Previous papers find large gender differences in the treatment effects, and in some instances only positive effects for women. I show that USI improves basic cognitive skills for both genders which is consistent with long-run effects of salt iodization for a sample of male draftees in Feyrer et al. (2017). More importantly, this study does not find that the treatment effects vary with gender preferences common to many countries in South and East Asia. This suggests that the policy has the potential to close gender gaps in learning outcomes in settings where women face discrimination. The results also emphasize the importance of access to iodized salt during early childhood as recent evidence does not find that adding fortified salt to school meals improves pupils' learning outcomes (Krämer et al., 2020).

In comparison with studies using the same data on test scores in rural India, USI raises cognitive skills at least as much as avoiding drought in utero and high contemporaneous air pollution, more than being exposed to a sanitation campaign (see Balakrishnan & Tsaneva (2021), Shah & Steinberg (2017) and Spears & Lamba (2016)) but less than 5 years of exposure to a school feeding program (see Chakraborty & Jayaraman (2019)). Vikram and Chindarkar (2020) evaluate the Integrated Child Development Services, a community-based integrated early childhood program in rural India which includes nutrition services. The food supplementation component of the program did not improve reading attainment but improved girls' numeracy score by 12.6% of a standard deviation. This is larger than the OLS results from this study but very similar to the IV estimates. Thus, USI appears to be a highly cost-effective way to improve children's cognition at scale, even in comparison to large-scale targeted early childhood nutrition interventions.

India was deemed iodine sufficient in 2016 but many low-income countries are still iodine deficient due to low consumption of adequately iodized salt (Iodine Global Network, 2017). Large effects of reaching USI can be expected for countries which have a very low proportion of households consuming iodized salt. This is of large policy importance as it is cognitive skills rather than schooling attainment which drive individual earnings and economic growth (Hanushek & Woessmann, 2008). Moreover, learning outcomes have remained poor in many developing countries despite increased school enrollment and attainment (Pritchett, 2001). A back of the envelope calculation using the lower bound effects found in this study, suggests that increasing the national coverage of iodized salt from 10% to 90% could increase the proportion of children attaining basic academic skills by at least 10%.

Declaration of Competing Interest

The author declares that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

A.1. Data Appendix

A.1.1. Goiter data

I use district level information on child goiter rate from the IDD and Nutrition Cell, Directorate of Health Services, Ministry of Health and Family Welfare India report shared with me by Kapil Yadav at the All India Institute Of Medical Science, to validate the location of historical goiter endemicity in McCarrison (1915). The data consists of district level averages of the goiter rate among primary school-aged children measured in 1940–2010. It is not representative at the state or country level and does not include all districts. Areas with previously known goiter prevalence are likely to have been included in the survey and surveyed earlier. Furthermore, it consists of surveys collected over a long period of time making it prone to measurement error.

To obtain a measure of the underlying intensity of naturally occurring iodine deficiency, I restrict the analysis of the goiter rate data to the 263 districts as of the 2001 Indian Census that were surveyed prior to the implementation of any district, state or national iodine fortification policies. The number of districts in India has increased over time. I match districts surveyed prior to 2001, to districts from the 2001 Census that were contained within the boundaries of the older districts. The matching of districts was made based on the reported divisions of districts throughout the 1971–2001 Indian Census by Kumar and Somanathan (2009). I also match districts of 2001 to the older districts given that the old district constitute at least 90% of the area of the new district. The sample of surveyed districts have an average total goiter rate (TGR) of 25.94 with a SD of 15.74, the proportion of children with goiter ranges from 0.01–85.35%. A kernel density graph of TGR per district is shown in Fig. 7. One notes the high density of TGR in the range of 20–40%, indicating a high TGR in the sampled districts.

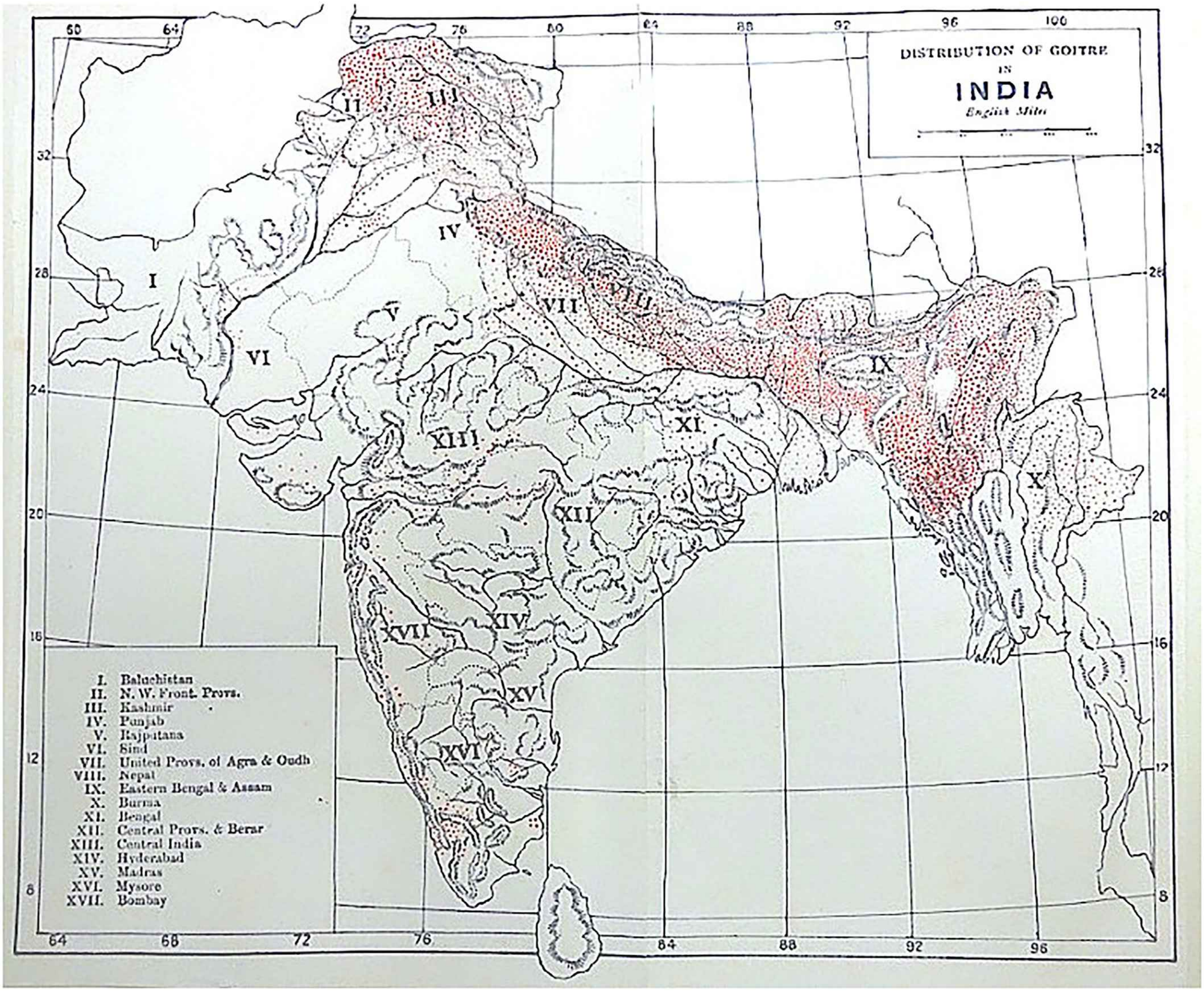

Fig. 6. Location of goiter endemic areas by McCarrison (1915). (This figure shows the location of historical goiter endemicity from McCarrison (1915). The dots represent areas which were found to be goiter endemic prior to 1915.)

The estimates are in line with historical data from other low- and middle-income countries, see Kelly and Snedden (1960). According to the WHO, mild endemicity corresponds to a prevalence of 5–19.9%, moderate to 20–29.90% and severe goiter endemicity to 30% or more (Aburto et al., 2014). Using the revised definitions, we observe that 24.33% of the surveyed school children in India prior to any salt iodization policies, had mild iodine deficiency, 27% were moderately iodine deficient and 36.50% have severe iodine deficiency. This dataset is used to validate the spatial prevalence of goiter in McCarrison (1915). Table A1 presents OLS results for the relationship between the historical endemicity measure in McCarrison (1915) and later district level child goiter rates (see Table A2).

CRediT authorship contribution statement

Wiktoria Tafesse: conceptualization, data curation, formal analysis, investigation, methodology, resources, software, visualization, writing - original draft, writing - review & editing.

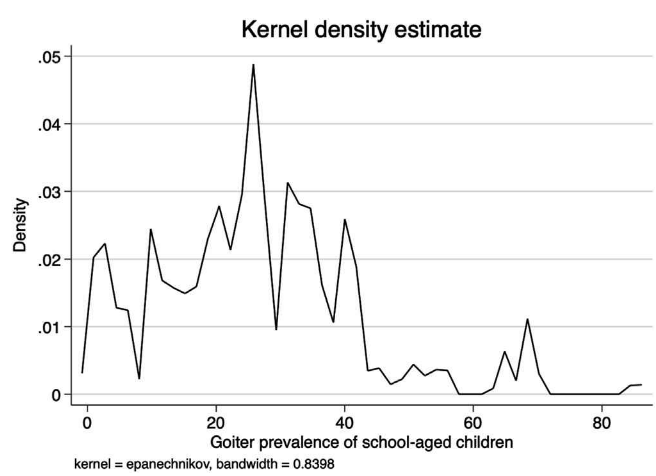

Fig. 7. Kernel density of goiter prevalence of school-aged children per district.

Table A1
Relationship between child goiter prevalence and historical goiter endemicity per district.

	(1) Historical Endemicity	(2) Historical Endemicity	(3) Historical Endemicity
Goiter rate	0.006***		
	(0.002)		
Goiter rate ⩾10%		0.251***	
		(0.085)	
Goiter rate ⩾20%			0.062
			(0.057)
Constant	0.476***	0.333***	0.516***
	(0.057)	(0.082)	(0.052)
Observations	262	582	582
R^2	0.037	0.015	0.002

Note. This table reports the coefficients from three separate linear probability models estimating the likelihood that a district has been identified as historically goiter endemic (containing at least one goiter endemic area from the map by McCarrison (1915)) on later district level goiter rate among children. This data stems from district level averages of the goiter rate among primary school-aged children measured during 1940–2010 by the IDD and Nutrition Cell, Directorate of Health Services, Ministry of Health and Family Welfare India. Robust standard errors are clustered on district. Rural district as of the 2001 Census and which are included in the ASER survey are included. Standard errors are shown in parentheses. * $p < .10$, ** $p < .05$, *** $p < .01$.

A.2. Cognitive test scores: Annual Status of Education Report

See Table A3 and Figs. 8, 9.

Table A2
Relationship between historical goiter endemicity and thyroid illness prevalence per state.

	(1) Current prevalence of thyroid problems	(2) Logarithm of current prevalence of thyroid problems	(3) Current prevalence of thyroid problems
Historical goiter endemic areas /state area	0.021**	1.424***	
	(0.009)	(0.479)	
Logarithm of historical goiter endemic areas /state area			0.003***
			(0.001)
Constant	0.012***	−4.805***	0.024***
	(0.003)	(0.175)	(0.005)
Observations	28	28	27
R^2	0.123	0.148	0.168

Note. This table reports the coefficients from three separate OLS models estimating the prevalence of individuals with thyroid related problems per state on the number of historical goiter areas per state and population. Data on the state level prevalence of thyroid related problems among individuals 35 years and older from the 2005–2006 NFHS IV is used for the analysis. The data is merged with the number of historical goiter endemic locations in McCarrison (1915) per area by 2011 Indian Census states. Robust standard errors are clustered on state. Standard errors are shown in parentheses. * $p < .10$, ** $p < .05$, *** $p < .01$.

A.3. Results

See Tables A4–A7.

Table A3
Descriptive statistics by gender: Children in early life before USI across goiter endemic and non-endemic districts.

	Endemic		Non-endemic	
	Mean	SD	Mean	SD
Panel A: Girls				
Numeracy Score	1.77	1.17	1.90	1.14
Age standardized numeracy score	−0.13	1.02	−0.03	0.98
Basic Numeracy (Single-digit number recognition)	0.85	0.36	0.89	0.31
Double-digit number recognition	0.56	0.50	0.61	0.49
Subtraction	0.27	0.44	0.30	0.46
Division	0.09	0.29	0.10	0.30
Literacy Score	1.97	1.37	2.15	1.33
Age standardized literacy score	−0.08	1.05	0.04	1.00
Basic Literacy (Letter recognition)	0.84	0.37	0.89	0.32
Word recognition	0.57	0.50	0.63	0.48
Class 1 reading comprehension	0.36	0.48	0.40	0.49
Class 2 reading comprehension	0.20	0.40	0.23	0.42
Enrolled in school	0.99	0.11	0.99	0.08
Grade	2.96	1.55	3.14	1.53
Enrolled in Private School	0.25	0.44	0.26	0.44
Private Tuition	0.18	0.38	0.16	0.36
Dropped out	0.00	0.07	0.00	0.06
Age	8.00	1.50	8.06	1.46
Maternal education (years)	3.89	4.45	4.27	4.53
Kutcha House	0.40	0.49	0.32	0.47
Pucca House	0.28	0.45	0.38	0.49
Household size	6.88	3.22	6.33	2.95
Primary school in village	0.92	0.26	0.93	0.25
Anganwadi in village	0.90	0.29	0.95	0.21
Pucca road in village	0.71	0.45	0.82	0.39
Ration shop in village	0.69	0.46	0.73	0.44
Observations	162187		98624	
Panel B: Boys				
Numeracy Score	1.84	1.19	1.92	1.14
Age standardized numeracy score	−0.05	1.02	0.01	0.97
Basic Numeracy (Single-digit number recognition)	0.86	0.34	0.90	0.31
Double-digit number recognition	0.58	0.49	0.62	0.48
Subtraction	0.29	0.45	0.30	0.46
Division	0.11	0.31	0.11	0.31
Literacy Score	1.98	1.35	2.11	1.31
Age standardized literacy score	−0.06	1.03	0.03	0.99
Basic Literacy (Letter recognition)	0.85	0.36	0.89	0.32
Word recognition	0.58	0.49	0.63	0.48
Class 1 reading comprehension	0.36	0.48	0.39	0.49
Class 2 reading comprehension	0.20	0.40	0.21	0.41
Enrolled in school	0.99	0.10	1.00	0.07
Grade	2.89	1.55	3.05	1.52
Enrolled in Private School	0.30	0.46	0.31	0.46
Private Tuition	0.20	0.40	0.17	0.38
Dropped out	0.00	0.06	0.00	0.05
Age	7.96	1.50	8.01	1.47
Maternal education (years)	3.85	4.45	4.21	4.52
Kutcha House	0.39	0.49	0.32	0.46
Pucca House	0.28	0.45	0.38	0.49
Household size	6.70	3.27	6.13	2.93
Primary school in village	0.92	0.27	0.93	0.25
Anganwadi in village	0.90	0.30	0.95	0.22
Pucca road in village	0.71	0.45	0.82	0.38
Ration shop in village	0.68	0.46	0.73	0.44
Observations	184382		112943	

Note. This table reports the means and standard deviations for children who were in early life during the absence of a nationwide USI policy, born in 2002–2004, in historically goiter endemic and non-endemic districts.

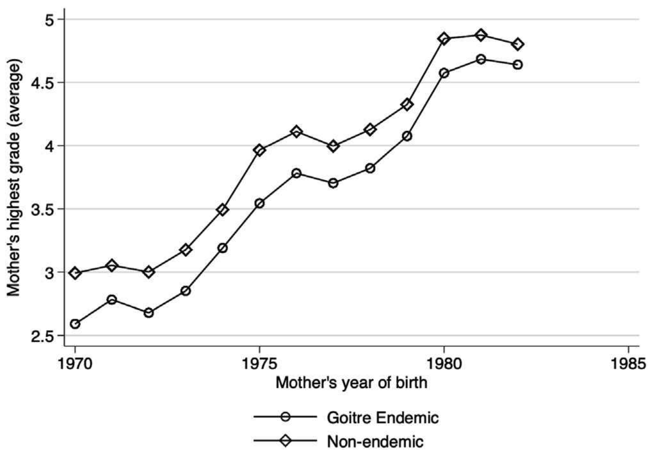

Fig. 8. Pre-trends in education. (This graph plots the trends in the average grade completed of mothers to the children surveyed in ASER, by their year of birth. Trends are shown prior to the access to iodized salt and by historical goiter endemicity of the district of residence.)

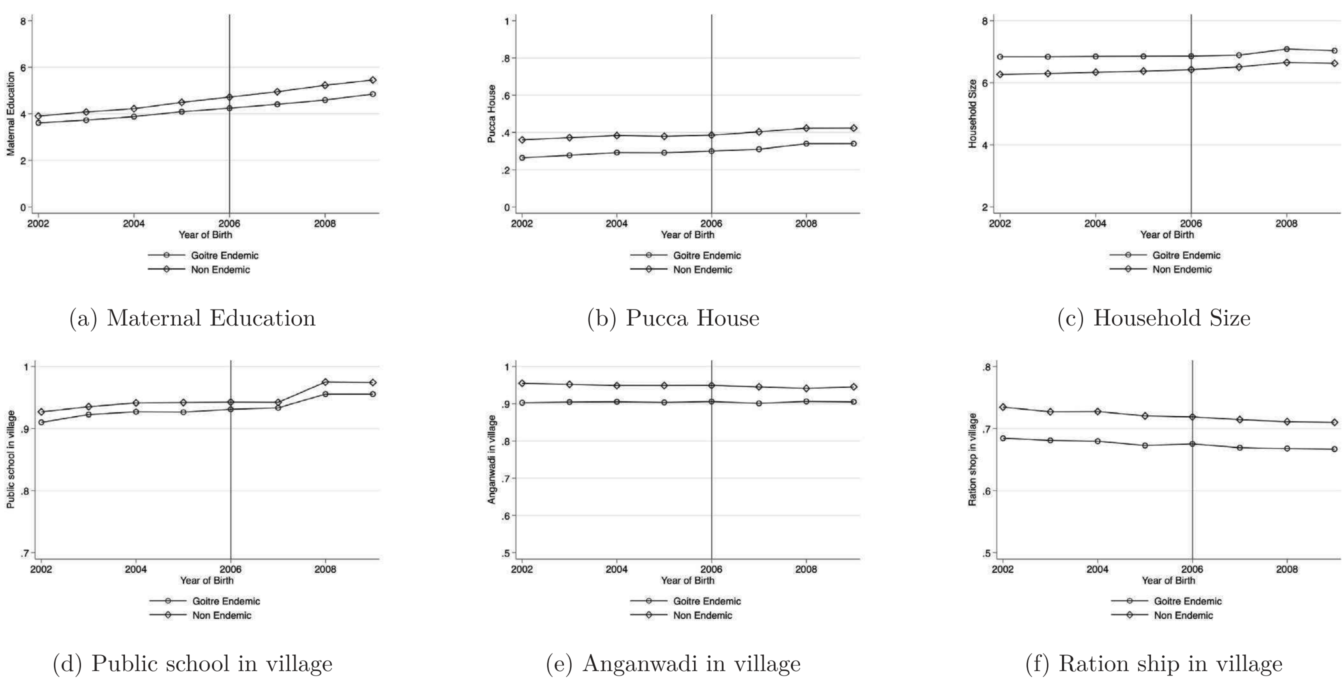

Fig. 9. Trends in cognitive test scores by birth year and goiter endemicity. (The figure shows trends in household and village characteristics by birth year and goiter endemicity using data from the Annual Status of Education Report.)

Table A4
Effect of USI in early life on cognitive test scores: Standard deviation of historical goiter endemic areas per district.

	Pooled				Girls				Boys			
	(1) Numeracy	(2) Numeracy	(3) Literacy	(4) Literacy	(5) Numeracy	(6) Numeracy	(7) Literacy	(8) Literacy	(9) Numeracy	(10) Numeracy	(11) Literacy	(12) Literacy
Panel A: Test Score												
USI * Endemic (SD goiter areas)	0.001	0.002	0.011	0.013	0.004	0.004	0.033**	0.032**	−0.002	0.001	−0.007	−0.004
	(0.012)	(0.011)	(0.013)	(0.012)	(0.012)	(0.012)	(0.016)	(0.016)	(0.015)	(0.014)	(0.014)	(0.013)
Controls		✓		✓		✓		✓		✓		✓
Observations	732215	732215	735688	735688	342505	342505	344108	344108	389710	389710	391580	391580
R^2	0.340	0.378	0.347	0.380	0.386	0.347	0.356	0.391	0.340	0.375	0.342	0.374
Panel B: Age-standardized test score												
USI * Endemic (SD goiter areas)	0.005	0.007	0.013	0.015	0.008	0.008	0.031**	0.031**	0.003	0.006	−0.003	0.000
	(0.011)	(0.011)	(0.011)	(0.010)	(0.011)	(0.011)	(0.014)	(0.013)	(0.015)	(0.013)	(0.012)	(0.011)
Controls		✓		✓		✓		✓		✓		✓
Observations	732215	732215	735688	735688	342505	342505	344108	344108	389710	389710	391580	391580
R^2	0.134	0.182	0.108	0.153	0.156	0.205	0.126	0.174	0.120	0.167	0.099	0.141
Panel C: Basic Skills												
USI * Endemic (SD goiter areas)	0.012***	0.012***	0.015***	0.015***	0.018***	0.018***	0.024***	0.024***	0.006	0.007	0.007	0.008
	(0.004)	(0.004)	(0.005)	(0.004)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
Controls		✓		✓		✓		✓		✓		✓
Observations	732215	732215	735688	735688	342505	342505	344108	344108	389710	389710	391580	391580
R^2	0.226	0.243	0.239	0.258	0.234	0.252	0.245	0.265	0.222	0.239	0.237	0.255

Note. This table reports the coefficients from Eq. 3 using the ASER data merged with historical information on the standard deviation of pre-fortification goiter endemic areas per district. The outcome variables are overall test scores, age-standardized test scores and basic skills in numeracy and literacy for children aged 5–10. The subsample of analysis and the type of skills are reported at the top of the table. The particular test score measure is reported in the first column from the left. The following fixed effects are included in all specifications; district, year of birth, survey year, survey year*year of birth and linear district trends. Columns 2, 4, 6, 8, 10 and 12 also include the following covariates; years of maternal education, household size, housing type, gender, primary school availability in village, anganwadi in village, village being connected to a pucca road and the presence of a ration shop in one's village of residence. Robust standard errors clustered on district are presented in parentheses. * $p < .10$, ** $p < .05$, *** $p < .01$.

Table A5
Effect of USI in early life on cognitive test scores: Standard deviation of historical goiter endemic areas per NSS region.

	Pooled				Girls				Boys			
	(1) Numeracy	(2) Numeracy	(3) Literacy	(4) Literacy	(5) Numeracy	(6) Numeracy	(7) Literacy	(8) Literacy	(9) Numeracy	(10) Numeracy	(11) Literacy	(12) Literacy
Panel A: Test Score												
USI * Endemic	−0.003	−0.001	0.010	0.012	0.001	0.004	0.036**	0.039**	−0.008	−0.006	−0.015	−0.013
(SD goiter areas /NSS region)	(0.017)	(0.016)	(0.015)	(0.015)	(0.016)	(0.015)	(0.017)	(0.016)	(0.022)	(0.021)	(0.019)	(0.019)
Controls		✓		✓		✓		✓		✓		✓
Observations	732215	732215	735688	735688	342505	342505	344108	344108	389710	389710	391580	391580
R^2	0.317	0.362	0.323	0.363	0.321	0.368	0.330	0.373	0.317	0.359	0.320	0.357
Panel B: Age-standardized test score												
USI * Endemic	0.003	0.005	0.014	0.016*	0.007	0.009	0.036***	0.038***	−0.000	0.002	−0.006	−0.005
(SD goiter areas /NSS region)	(0.010)	(0.009)	(0.010)	(0.010)	(0.011)	(0.010)	(0.012)	(0.012)	(0.013)	(0.013)	(0.013)	(0.012)
Controls		✓		✓		✓		✓		✓		✓
Observations	732215	732215	735688	735688	342505	342505	344108	344108	389710	389710	391580	391580
R^2	0.103	0.161	0.077	0.131	0.122	0.182	0.090	0.149	0.089	0.145	0.068	0.119
Panel C: Basic Skills												
USI * Endemic	0.018***	0.018***	0.021***	0.021***	0.020***	0.020***	0.027***	0.027***	0.015***	0.016***	0.015***	0.016***
(SD goiter areas /NSS region)	(0.004)	(0.003)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.005)	(0.005)	(0.005)	(0.005)
Controls		✓		✓		✓		✓		✓		✓
Observations	732215	732215	735688	735688	342505	342505	344108	344108	389710	389710	391580	391580
R^2	0.226	0.243	0.239	0.258	0.234	0.252	0.245	0.265	0.222	0.239	0.237	0.255

Note. This table reports the coefficients from Eq. 3 using the ASER data merged with historical information on goiter endemicity per NSS region. The outcome variables are overall test scores, age-standardized test scores and basic skills in numeracy and literacy for children aged 5–10. The subsample of analysis and the type of skills are reported at the top of the table. The particular test score measure is reported in the first column from the left. The following fixed effects are included; NSS region, year of birth, survey year, survey year*year of birth and linear NSS trends. Columns 2, 4, 6, 8, 10 and 12 also include the following covariates; years of maternal education, household size, housing type, gender, primary school availability in village, anganwadi in village, village being connected to a pucca road and the presence of a ration shop in one's village of residence. Robust standard errors clustered on NSS regions and are presented in parentheses. * $p < .10$, ** $p < .05$, *** $p < .01$.

Table A6
Effect of USI in early life on private school enrollment and tuition.

	Pooled		Girls		Boys	
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Private school enrollment						
USI * Endemic	−0.003	0.001	0.004	0.004	−0.009	−0.002
	(0.007)	(0.006)	(0.009)	(0.009)	(0.009)	(0.009)
Controls		✓		✓		✓
Observations	738693	738693	344415	344415	394278	394278
R^2	0.180	0.263	0.177	0.258	0.191	0.269
Panel B: Taking private tuition						
USI * Endemic	0.003	0.005	−0.000	0.001	0.006	0.008
	(0.005)	(0.005)	(0.007)	(0.007)	(0.008)	(0.008)
Controls		✓		✓		✓
Observations	740943	740943	344450	344450	396493	396493
R^2	0.182	0.206	0.186	0.208	0.183	0.206

Note. This table reports the coefficients from Eq. 3 using the ASER data for children aged 5–10, merged with historical information on district level goiter endemicity. The outcome variables are reported on the left-hand side column. The subsample of analysis is reported at the top of the table. The following fixed effects are included in all regressions: district, year of birth, survey year, survey year*year of birth and linear district trends. Columns 2, 4 and 6 also include the following covariates; years of maternal education, household size, housing type, gender, primary school availability in village, anganwadi in village, village being connected to a pucca road and the presence of a ration shop in one's village of residence. Robust standard errors clustered on district are presented in parentheses. * $p < .10$, ** $p < .05$, *** $p < .01$.

Table A7
Effect of USI in early life on cognitive test scores by son preference.

	Pooled				Girls				Boys			
	(1) Numeracy	(2) Numeracy	(3) Literacy	(4) Literacy	(5) Numeracy	(6) Numeracy	(7) Literacy	(8) Literacy	(9) Numeracy	(10) Numeracy	(11) Literacy	(12) Literacy
Panel A: Test Score												
USI * Endemic	−0.003	0.004	0.011	0.019	0.018	0.013	0.079*	0.073*	−0.019	−0.001	−0.045	−0.025
	(0.028)	(0.028)	(0.033)	(0.032)	(0.036)	(0.035)	(0.043)	(0.042)	(0.035)	(0.035)	(0.041)	(0.040)
USI * Above median sex ratio	−0.050*	−0.046	−0.069*	−0.066*	−0.055	−0.057	−0.038	−0.043	−0.045	−0.035	−0.091**	−0.081*
	(0.029)	(0.029)	(0.036)	(0.036)	(0.039)	(0.039)	(0.049)	(0.048)	(0.038)	(0.037)	(0.044)	(0.043)
USI * Endemic * Above median sex ratio	0.029	0.019	0.058	0.048	0.010	0.018	−0.013	−0.003	0.040	0.016	0.111*	0.085
	(0.040)	(0.039)	(0.046)	(0.045)	(0.050)	(0.049)	(0.061)	(0.061)	(0.050)	(0.049)	(0.057)	(0.055)
Controls		✓		✓		✓		✓		✓		✓
Observations	715983	715983	719335	719335	334916	334916	336452	336452	381067	381067	382883	382883
R^2	0.339	0.377	0.346	0.379	0.346	0.385	0.355	0.391	0.338	0.374	0.341	0.373
Panel B: Age-standardized test score												
USI * Endemic	0.009	0.016	0.018	0.024	0.026	0.021	0.075**	0.070*	−0.003	0.015	−0.028	−0.011
	(0.026)	(0.026)	(0.027)	(0.027)	(0.034)	(0.033)	(0.037)	(0.036)	(0.033)	(0.032)	(0.034)	(0.033)
USI * Above median sex ratio	−0.038	−0.034	−0.050*	−0.047	−0.041	−0.043	−0.020	−0.024	−0.034	−0.025	−0.072*	−0.063*
	(0.027)	(0.027)	(0.030)	(0.029)	(0.036)	(0.036)	(0.041)	(0.040)	(0.036)	(0.036)	(0.037)	(0.036)
USI * Endemic * Above median sex ratio	0.014	0.005	0.039	0.031	−0.002	0.005	−0.021	−0.013	0.023	0.000	0.084*	0.062
	(0.037)	(0.037)	(0.039)	(0.038)	(0.047)	(0.046)	(0.052)	(0.051)	(0.048)	(0.047)	(0.048)	(0.047)
Controls		✓		✓		✓		✓		✓		✓
Observations	715983	715983	719335	719335	334916	334916	336452	336452	381067	381067	382883	382883
R^2	0.133	0.182	0.108	0.154	0.155	0.204	0.126	0.174	0.119	0.166	0.099	0.142
Panel C: Basic Skills												
USI * Endemic	0.030**	0.032***	0.023*	0.024**	0.042***	0.041***	0.043***	0.041***	0.022	0.026*	0.007	0.011
	(0.012)	(0.012)	(0.012)	(0.012)	(0.015)	(0.015)	(0.014)	(0.014)	(0.014)	(0.014)	(0.014)	(0.014)
USI * Above median sex ratio	0.004	0.005	−0.001	−0.000	0.011	0.011	0.011	0.010	−0.000	0.002	−0.010	−0.008
	(0.013)	(0.013)	(0.013)	(0.013)	(0.015)	(0.015)	(0.015)	(0.015)	(0.016)	(0.016)	(0.016)	(0.015)
USI * Endemic * Above median sex ratio	−0.016	−0.018	0.003	0.001	−0.022	−0.020	−0.014	−0.012	−0.013	−0.019	0.016	0.010
	(0.017)	(0.017)	(0.018)	(0.018)	(0.020)	(0.020)	(0.021)	(0.021)	(0.021)	(0.021)	(0.021)	(0.021)
Controls		✓		✓		✓		✓		✓		✓
Observations	715983	715983	719335	719335	334916	334916	336452	336452	381067	381067	382883	382883
R^2	0.226	0.243	0.238	0.257	0.234	0.252	0.245	0.265	0.222	0.239	0.236	0.254

Note. This table reports the coefficients from a similar specification to Eq. 3, but the treatment variable is now interacted with the district level standardized sex ratio. I use the ASER data merged with historical information on district level goiter endemicity. The sex ratio data stems from the 2001 Indian Census and represents the number of girls to 1000 boys aged 0–6 years. The independent variable of interest is the interaction term between benefiting from iodine fortification and one's sex ratio per district. The outcome variables are overall test scores, age-standardized test scores and basic skills in numeracy and literacy for children aged 5–10.. The subsample of analysis and the outcome variables are reported at the top of the table. The following fixed effects are included in all regressions; district, year of birth, survey year, survey year*year of birth and linear district trends. Columns 2, 4, 6, 8, 10 and 12 also include the following covariates; years of maternal education, household size, housing type, gender, primary school availability in village, anganwadi in village, village being connected to a pucca road and the presence of a ration shop in one's village of residence. Robust standard errors clustered on district are presented in parentheses. * p < .10, p** < .05, *** p < .01.

A.4. Robustness

See Tables A8–A10.

Table A8
Effect of USI in early life on cognitive test scores controlling for trends in district level baseline covariates.

	Pooled				Girls				Boys			
	(1) Numeracy	(2) Numeracy	(3) Literacy	(4) Literacy	(5) Numeracy	(6) Numeracy	(7) Literacy	(8) Literacy	(9) Numeracy	(10) Numeracy	(11) Literacy	(12) Literacy
Panel A: Test Score												
USI * Endemic	0.008	0.007	0.037	0.036	0.018	0.001	0.069**	0.058*	0.001	0.014	0.006	0.017
	(0.019)	(0.020)	(0.023)	(0.024)	(0.024)	(0.026)	(0.030)	(0.032)	(0.024)	(0.025)	(0.028)	(0.030)
Early NREGS * year of birth	✓		✓		✓		✓		✓		✓	
Baseline district-level characteristics * year of birth		✓		✓		✓		✓		✓		✓
Observations	730052	695691	733515	698861	341457	325363	343055	326821	388595	370328	390460	372040
R^2	0.378	0.375	0.380	0.378	0.386	0.382	0.391	0.390	0.375	0.372	0.374	0.372
Panel B: Age-standardized test score												
USI * Endemic	0.014	0.012	0.035*	0.033	0.020	0.004	0.062**	0.051*	0.010	0.021	0.011	0.018
	(0.018)	(0.019)	(0.019)	(0.020)	(0.023)	(0.024)	(0.025)	(0.027)	(0.023)	(0.024)	(0.024)	(0.025)
Early NREGS * year of birth	✓		✓		✓		✓		✓		✓	
Baseline district-level characteristics * year of birth		✓		✓		✓		✓		✓		✓
Observations	730052	695691	733515	698861	341457	325363	343055	326821	388595	370328	390460	372040
R^2	0.182	0.178	0.153	0.152	0.205	0.200	0.173	0.173	0.167	0.163	0.141	0.140
Panel C: Basic Skills												
USI * Endemic	0.024***	0.024***	0.026***	0.021**	0.032***	0.032***	0.037***	0.034***	0.018*	0.019*	0.017*	0.011
	(0.009)	(0.009)	(0.009)	(0.009)	(0.010)	(0.010)	(0.010)	(0.011)	(0.010)	(0.010)	(0.010)	(0.010)
Early NREGS * year of birth	✓		✓		✓		✓		✓		✓	
Baseline district-level characteristics * year of birth		✓		✓		✓		✓		✓		✓
Observations	730052	695691	733515	698861	341457	325363	343055	326821	388595	370328	390460	372040
R^2	0.244	0.243	0.258	0.257	0.252	0.251	0.265	0.264	0.239	0.239	0.255	0.254

Note. This table reports the coefficients from Eq. 3 using the ASER data merged with historical information on district level goiter endemicity. The outcome variables are overall test scores, age-standardized test scores and basic skills in numeracy and literacy respectively for children aged 5–10. The subsample of analysis and the type of skills are reported at the top of the table. The particular test score measure is reported in the first column from the left. The following fixed effects are included in all specifications; district, year of birth, survey year, survey year*year of birth and linear district trends, years of maternal education, household size, housing type, gender, primary school availability in village, anganwadi in village, village being connected to a pucca road and the presence of a ration shop in one's village of residence. Robust standard errors clustered on district are presented in parentheses. * $p < .10$, ** $p < .05$, *** $p < .01$.

Table A9
Placebo regression: The effect of USI on health related outcomes.

	(1) BCG	(2) Measles	(3) Vitamin A	(4) Had Diarrhea
USI * Endemic	−0.057**	−0.006	−0.006	0.003
	(0.028)	(0.033)	(0.033)	(0.013)
Mother's Education	0.009***	0.007***	0.007***	0.000
	(0.001)	(0.000)	(0.000)	(0.000)
Primary school in village	0.021***	0.018***	0.018***	−0.008**
	(0.006)	(0.005)	(0.005)	(0.004)
Girl	−0.012***	−0.009***	−0.009***	−0.006***
	(0.002)	(0.002)	(0.002)	(0.002)
Anganwadi in village	0.019***	0.011***	0.011***	0.001
	(0.005)	(0.004)	(0.004)	(0.003)
Semi-Pucca House	0.037***	0.025***	0.025***	0.001
	(0.003)	(0.003)	(0.003)	(0.002)
Pucca House	0.044***	0.037***	0.037***	−0.001
	(0.005)	(0.004)	(0.004)	(0.003)
Observations	175567	175507	175507	175170
R^2	0.587	0.472	0.472	0.194

Note. Data from the DLHS 2 and DLHS 3 is used for the analysis. All specifications include controls for: district, year of birth, interview year, interview year*year of birth and linear district trends. Robust standard errors clustered on district in parentheses. * $p < .10$, ** $p < .05$, *** $p < .01$.

Table A10
Representative first stage: Ecological determinants of historical goiter endemicity.

	(1) USI * Goiter Endemic District
USI * Distance to coast from district centroid (100 km)	0.052***
	(0.006)
USI * Maximum elevation per district (km)	−0.018
	(0.015)
USI * Average rainfall per district 1951–2001 (1000 mm)	0.038***
	(0.010)
Observations	696915
R^2	0.0576

Note. This table shows the representative first stage estimates for the corresponding IV regression for the numeracy score for the pooled sample controlling for the full set of covariates (district, year of birth, survey year, survey year*year of birth and district specific linear trends, years of maternal education, household size, housing type, gender, primary school availability in village, anganwadi in village, village being connected to a pucca road and the presence of a ration shop in one's village of residence). The instruments are interacted with USI since it is USI*Endemic that is to be predicted as with Endemic and USI, the main effects are subsumed in the district and birth year fixed effects. Mean (SD): Distance to coast 5.33 (3.24), maximum elevation 0.71 (1.03), average rainfall 5.08 (2.20). Table 7 includes all relevant details regarding robust first stage F statistics. Robust standard errors clustered on district are shown in parentheses. * $p < .10$, ** $p < .05$, *** $p < .01$.

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