A Bit of Salt, A Trace of Life:
Long-Run Impacts of Salt Iodization in China

Zichen Deng* Maarten Lindeboom†

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Abstract

In 1994, China implemented the national program of regulating salt to contain iodine, a key micronutrient in development of cognitive ability. After the adoption of the new salt, individuals' access to iodine improved dramatically. We compare the human capital development of cohorts born before and after the salt iodization in areas with varying pre-intervention iodine deficiency prevalence (goiter rates). For females in the rural area, a one standard deviation reduction in goiter rates results in a roughly 15% increase in cognitive ability measured by standardized math and verbal tests. Females who benefit from the new salt also obtain 0.5 additional years of schooling and have a higher educational attainment. Yet, we don't find significant effects for males for both cognitive ability and educational outcomes. Therefore, we see a substantial reduction of the gender (notably math) ability gap. For females, the gains are highest in neighborhood with strongest son preferences, suggesting that health interventions have the largest impact among those received limited parents' investment.

KeyVerbals: Fetal origins, iodine, cognitive ability, gender attitudes.
JEL: I15, I18, J24, O15

1 Introduction

Essential micronutrients such as iodine, iron and zinc are critical for human growth and development. High costs in terms of poor health in low-income countries partly result from inadequate access to these micronutrients. In particular, iodine deficiency early in pregnancy has significant, irreversible effects on brain development (Cao et al., 1994), and therefore has important consequences for human capital formation. Although the benefits of micronutrient improvement have been documented for decades, children in many countries take in insufficient iodine over a long time. Great progress has been made since the primary intervention strategy for Iodine Deficiency Disorders (IDD) control - Universal Salt Iodization (USI) - was adopted in 1993. This worldwide intervention initiated by the World Health Organization (WHO) is very successful, and is hailed as a major public health triumph that ranks with eradicating smallpox and poliomyelitis. Twenty years after WHO initialed the campaign, around 66% of households now have access to iodized salt globally.[1] However, very limited direct long-run evidences for the effectiveness of such an

*Vrije Universiteit Amsterdam and Tinbergen Institute, zichen.deng@vu.nl
†Vrije Universiteit Amsterdam and Tinbergen Institute, m.lindeboom@vu.nl
[1]Source: UNICEF (http://www.who.int/nutrition/topics/idd/en/)

important public health intervention exists, except some historical studies looking into Switzerland and the U.S. in 1920s.[2] What can we learn from recent campaigns in developing countries against Iodine Deficiency Disorders (IDD) initiated by the World Health Organization (WHO)? The knowledge gained from such research would benefit countries which have already adopted iodized salt and countries which might adopt it in the future. Furthermore, in countries adopted USI after the 1993 campaign, individuals exposed to such an intervention in utero are now in their middle or late childhood, an age group that is often neglected by the "early-origin" literature due to the data availability (the "missing middle" in Almond, Currie, and Duque, 2017). What can we observe from individuals in their middle or late childhood after such an early-life intervention? Although economists mainly focus on adult outcomes like earning, the lack of evidences in childhood restricts our understanding on how developmental trajectories unfold over the life course. More importantly, one challenge of the long-run effects literature is that long-term outcomes are unobserved in the time frame needed to make policy decisions. Therefore, evidences of childhood outcomes would be surrogates to researchers when evaluating the effectiveness of similar interventions under a timely scheme. All these questions have received rare attention, and are the focus of the current study.

This study attempts to provide answers to the questions above by looking at the salt iodization policy in China. To fight against iodine deficiency diseases around the country, the Chinese government implemented the national program of regulating salt to contain iodine in October, 1994. In the second year, biennial province-based monitoring was introduced to record the use and iodine content of household salt, along with urinary iodine concentrations among schoolchildren from the same households. After the introduction of the program, the urinary iodine concentration reached satisfactory levels from 1995 onward and the percentage of children who had goiter dropped rapidly. The present study exploit the plausibly exogenous variation comes from such targeted intervention in public health. We examine the impact of this policy on indicators of human capital accumulation at middle or late childhood. Given evidence from previous studies on the importance of fetal iodine, we focus on the potential impact of this policy on children affected while in utero.

We do this by linking iodine deficiency information across locations collected at the beginning of the intervention to nationally representative rural samples drawn from the *China Family Panel Studies* (CFPS). A unique aspect of the survey (CFPS) is that math and vocabulary ability from standardized tests were collected besides information on educational attainments and schooling. Similar to Shah and Steinberg (2017), our human capital measurements in the CFPS have the advantage that the same questions were given to each individual in the survey, no matter whether he/she is currently enrolled in school or not. This is rare in data sets from developing countries, where information is often only available for individuals enrolled in school. Using this data set, our empirical design does not suffer from selection bias caused by censoring individuals who had already quit school. To identify the long-term benefits of the salt iodization policy, we use the national salt iodization program as a quasi-experiment and exploit geographic variation in goiter prevalence prior to the intervention. We compare improvements in math and vocabulary ability and also educational attainment of cohorts born before and after the salt iodization in areas with varying pre-intervention goiter prevalence.

Our difference-in-differences estimates find that the salt iodization policy has dramatically decreased the gap in females' human capital accumulation between provinces of high and low goiter prevalence. A one standard deviation decrease in the pre-intervention child goiter rate is associated with math and vocabulary test scores increasing by roughly 15% for the pooled sample of females of two waves in 2010 and 2014. We

[2] These studies (Politi, 2015; Adhvaryu et al., 2016; Feyrer, Politi, and Weil, 2017) found cohorts exposed to the new salt early in life have higher labor force participation, income and also a higher probability to enter top-tier occupations with higher cognitive demands.

standardized math and vocabulary ability of individuals currently in and out of school were collected both.

Thirdly, we also speak to recent interests in dynamic complementary of human capital formation. Although it is very important to policy makers, the causal evidence of such complementary is very limited due to the high demands of identification (which needs "lightning to strike" twice Almond, Currie, and Duque, 2017). Causal inference on dynamic complementary requires: (1) exogenous variation in the baseline stock; (2) exogenous variation in subsequent investment. Researchers can then pinpoint the effects from the interaction of two shocks on the return to human capital. In our exercises, we leverage son preferences across regions to have plausible exogenous variation in parents' investment. In that sense, our studies share a similar spirit with the strategy that looks at differences in the returns to human capital of positive shocks across subgroups (Bhalotra and Venkataramani, 2013, 2015).

Finally, we also shed light on the literature about gender bias, particularly in the east Asian context. In our current study, we only find effects for females, which echoes results from many studies in the Asian context. However, other studies from the "fetal origins" literature often find males experience larger impacts, which suggests male fetuses are more fragile and sensitive to nutritional insults. Our results looking at heterogeneous impacts supports that variation in son preference across countries contributes to these differences. Therefore, our study integrates work on gender inequality into work on "fetal origins".

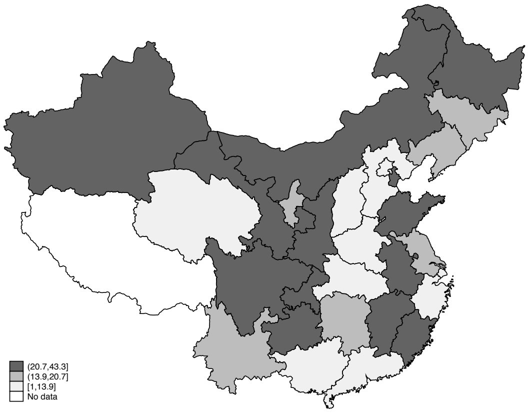
The rest of the paper is organized as follows. Section 2 provides a brief overview of Iodine Deficiency Disorders (IDD), the Universal Salt Iodization (USI) and the related literature. Section 3 provides a description of the data used in the analysis. Section 4 outlines the various econometric models used, and Section 5 discusses the results of those models. Section 6 discusses the interaction of early-life shocks with later life parental investment. The final section 7 presents concluding remarks.

2 Background

Iodine is an essential component of the hormones produced by the thyroid gland, and therefore is essential of human life (Zimmermann, 2011). From the fetal stage to adulthood, insufficient iodine intake causes many disorders, the most common of which is an enlargement of the thyroid gland. Although this enlargement, which is called goiter, is the most visible symptom of iodine deficiency, the most important consequence of iodine deficiency is impaired neuro-development, particularly early in life. The brain damage caused by iodine deficiency is often irreversible. This study focuses on the availability of iodine in utero and estimates the long-term impact on cognitive ability and school attainment of improving the intrauterine health policy.

The knowledge that iodine can help prevent goiter has existed since the mid-1800's (Zimmermann, 2008). It was not until 1895, however, that iodine was first discovered in the thyroid gland (Baumann, 1896). Switzerland was the first country in the world to introduce iodized salt in 1922. U.S. introduced iodized salt in 1924 after executive Council of the Michigan State Medical Society officially endorsed salt. Globally, an estimated 2 billion people are unprotected from iodine deficiency and its related disorders (IDD) which include mental impairment, cretinism, and goiter (Zimmermann, 2011). In 1993, World Health Organization (WHO) proposed a worldwide campaign to eradicate IDD. The primary intervention strategy for IDD control is indeed Universal Salt Iodization (USI), which is a notably simple, universally effective, wildly attractive and particularly cheap technical instrument. The World Bank reports that it would only cost approximately $0.05 per child per year.

Historically, endemic goiter was found particularly in mountain region in China. For instance in 1940s, more than 20% residents of Kunming, the capital of Yunnan provinces, had goiter (Simoons, 1990). The



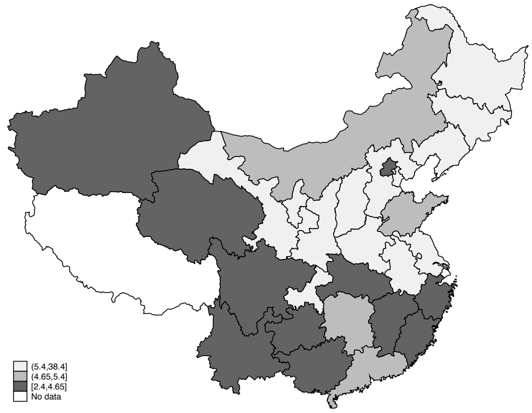


Figure 1. Goiter Distribution in 1995 **Figure 2.** Iodine Contents in Water

Notes: Figure 1 and 2 report goiter rates (among schoolchildren aged 8-10) in 1995 and iodine contents in water across provinces, respectively. Darker areas represent higher goiter rates or lower iodine contents in the water, respectively.
Sources: National Iodine Survey

iodine deficiency disorder (IDD) problem was acknowledged as a public health threat early during the 1990s. The Chinese Academy of Preventive Medicine had estimated that about 450 million people lived in iodine-deficient areas, with more than 30% of the population considered at risk of IDD (see Chen and Wu, 1998).

In 1993, the State Council of China announced the policy to virtually eliminate iodine deficiency disorders (IDD) by 2000 and adopted the Universal Salt Iodization (USI) as the national strategy. From 1st October 1994 the State Council enacted the national specifications for salt iodization to eliminate health hazards due to iodine deficiency in China. Between 1993 and 1995, a national monitoring system was built to track trends in goiter prevalence among aged 8-10 schoolchildren. The first national wide survey in 1995 was carried between March and June.[4]

The map on the left in Figure 1 illustrates the geographic distribution of goiter rate (among schoolchildren aged 8-10) across the whole country with higher goiter rates from upland area in the west. But eastern provinces is not spared, even some coastal provinces have high goiter rates. The national iodine survey also collect information of iodine contents in drinking water in 1997 and 2002, which is visualized in Figure 2. We can notice that the spatial distribution of goiter generally correlates the distribution of iodine content in water sources for inland provinces, while goiter rates are low for coastal provinces even if the iodine content in water is low.[5] Drinking water in provinces close to the ocean tend to be rich in iodine, however, there are still coastal provinces have low iodine contents in water. With all information above, a nature robustness check (Panel B of Table 3) is to use an instrumental variable approach, where iodine contents in water and whether the province is close to the ocean are two instruments of our main iodine deficiency measurements (goiter rates). We can also notice that the graph also show considerable variation in goiter prevalence across provinces even within different regions.[6]

[4]One concern is that the goiter data is not measuring the pre-intervention iodine deficiency prevalence, since the survey was carried 5-8 months later than the official starts of salt iodization. As pointed out by the literature, there is a well-known lag before the goiter rate normalizes after iodine repletion. For example, Zimmermann et al. (2003) documented nonsignificant reduction in thyroid size among children age 8-9 in Cote d'Ivoire one year after the introduction of the iodinzed salt. Even two years after the salt intervention, they only see an 8% reduction in the goiter rate. Therefore, given the survey was only 5-8 months later than the start of the intervention, we have the confidence that our goiter data from the survey is still a good measure of the iodine deficiency prevalence before the intervention.

[5]The caveat of data on iodine content in water is the sample size. In each province, only around 30 samples of drinking water were collected.

[6]For the list of provinces by region, see Table A2 in Appendix A or National Bureau of Statistics of China.

Another concern of previous studies in the literature is the level of salt iodization. Currently, the WHO recommends a level of 20-40 mg/kg in the manufacturer's supply outlets, while interventions in developed countries in 1920s introduced salt contained much lower level than the recommended now (for instance, Sweden regulated salt to have 10mg/kg iodine at the beginning). If the salt doesn't contains enough iodine, the effects might be too small to be pin pointed. Furthermore, those countries increased the level of the iodine in the salt gradually, which further complicates the identification. To reach the desired intake of iodine, the level of salt iodization in China during manufacturing was set at 50 mg/kg in 1994 to ensure a level of not less than 40 mg/kg in the manufacturer's supply outlets. The level set by the regulation looks reasonable, but what we want to know ultimately is the level of iodine intakes by individuals. Urinary iodine concentration information would be an ideal measurements. Along with measuring goiter rates among schoolchildren, those iodine surveys also measured the urinary iodine concentration of (part of) those children. The national median urinary iodine concentration reaches 160 µg/L in 1995 (23 provinces) and progressed to 300 µg/L in 1997 (31 provinces) and 282 µg/L in 1999 (31 provinces). WHO classifies 100–199 µg/L as an adequate iodine nutrition level.[7] Information above suggests that our identification would suffer smaller bias comparing to what the literature had.

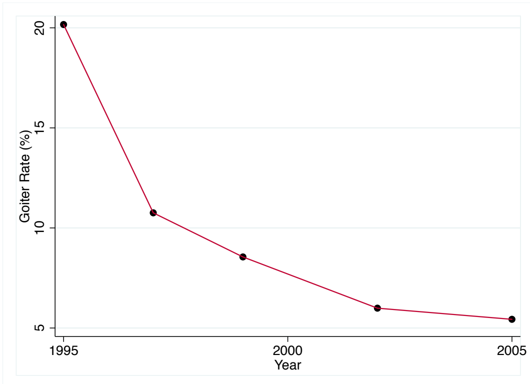
3 Data

3.1 Goiter Data

Our information on the geographic distribution of goiter prevalence before salt iodization comes from the data used to create Figures 1 and 2: the 1995 national survey on goiter rates among schoolchildren. In each provincial survey, a multistage, probability proportionate to population size cluster sample was obtained. The county served as the primary sampling unit, and 30 counties (clusters) were selected systematically in each province from a county population list. In each selected county, a school was then sampled at random. Children aged 8 to 10 years (in 1995) served as the index population. For each cluster, 40 children were selected at random from the enrollment list. All children were examined for thyroid size by palpation and/or ultrasound. The sample sizes by province ranged from 1,200 to 2,400 (mean, 1,259) in 1995. Therefore, our goiter data has an important advantage over the literature. Many studies use goiter prevalence among military recruits, where the index population are usually young healthy men and, therefore, not a representative measure of the local iodine deficiency problem. We use province-level goiter rates, since we only know the province of birth, but not the county of birth, of the individuals in our sample.

After the adoption of Universal Salt Iodization (USI) in 1995, large declines in goiter prevalence were documented. By 2002, provinces converged to very low child goiter rates, so that provinces with high pre-eradication levels of goiter experienced the largest reductions. We use biennial province-based survey data from 1995 to 2005 to show the progress. Figure 3 shows the (unweighted) average goiter rate (%) across the whole country over this time period. The average goiter rate decreases from 20% in 1995 to around 5% in 2005. Figure 4 shows the post-campaign decline in goiter rate versus pre-campaign levels. Our basic assumption, that areas where IDD was highly endemic saw a greater drop in IDD than areas with a low goiter rate, indeed holds.

[7] Source: http://apps.who.int/iris/bitstream/10665/85972/1/WHO_NMH_NHD_EPG_13.1_eng.pdf



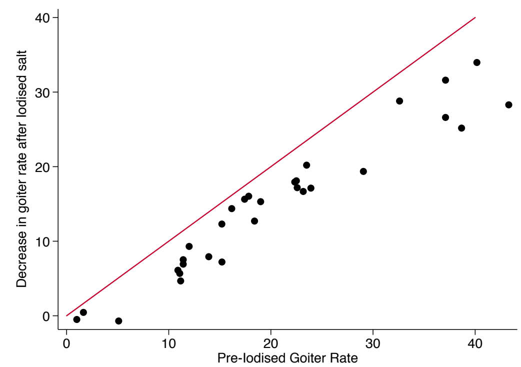


Figure 3. Goiter Rates Decline **Figure 4.** Before and After the Intervention

Notes: Figure 3 reports time-series data on mean goiter rate (among schoolchildren aged 8-10) across country between 1995 to 2005. Figure 4 shows the post-intervention decline in goiter rate versus pre-intervention levels across China.
Sources: National Iodine Survey

3.2 Outcomes and Control Variables

The micro-level data employed in the present study come from the *China Family Panel Studies* (CFPS). CFPS is a large-scale nationally representative panel survey project conducted by the Institute of Social Science Survey at Peking University. Three waves of survey have been published until 2017. Through a multistage probability sampling procedure, the CFPS baseline wave (hereafter CFPS-2010) selects a total of 14,798 households. A second and third wave of the CFPS followed the same individual from those households in 2012 and 2014 (hereafter CFPS-2012 and CFPS-2014). In CFPS-2010 and CFPS-2014, standard math and verbal tests were carried. And all three waves educational attainments information were recorded. The data collect very clear birth information including province of birth, year and month of birth.[8] Information of registration is also recorded whether respondents were born in rural area. We restrict our sample to individuals born in rural area between 1991 July and 2000 June, which means we have four cohorts conceived before and after the intervention. The reason of focusing on such group is: firstly, individuals older are more likely to have moved out of the household; secondly, we want to target on individual who born just before and after the introduction of iodized salt. After dropping some individual losing part of key information, we have 6790 observations altogether.

Educational attainment is an ordered categorical variable, which equals one to four representing illiterate, graduated from primary school, middle school and high school, respectively. Schooling is measured by years in school. As alternative measures of human capital, a math test is designed by the CFPS team. The math test consists of twenty-four mathematical problems, drawn from textbooks used in primary and secondary schools, with two items corresponding to the math materials taught in each grade. Questions were sorted in order of increasing difficulty and each those questions counted for one point. Similarly, the verbal test consists of thirty-four Chinese characters drawn from the language textbooks. Questions in both tests were sorted in order of increasing difficulty and each those questions counted for one point. Therefore, full scores are 24 and 34 for math and verbal tests respectively.

Table 1 reports summary statistics for our sample population using the CFPS-2010 and CFPS-2014. We pool male and female together.[9] The first two column summarizes our outcome variables for the sample

[8]The survey also collects respondents' migration history. Migration before age 3 is very low (small than 3%).
[9]Summary statistics for female can be found in Table A1.

in high goiter provinces[10] with the first column contains all individual conceived before intervention and the second after. Similarly, column third and forth contains all individual in low goiter provinces. Parental education are also ordered categorical variables as educational attainment, but we only report mean here to save some spaces. For both pre- and post-intervention cohorts, we don't see significant differences in demographics, parental characteristics and other control variables between high and low goiter area. The public health intervention took place during a period of tremendous expansion in economy, it's important for our empirical strategy to explore possible confounders like pubic health investment expansion. Therefore, we supplement individual controls with several characteristics of province of birth such as: number of hospitals per capita and number of hospital beds per capita. Such information are collected from National Bureau of Statistics of China. In the last row, gender attitudes index is calculated using self-reported information in CFPS-2014. Details about how to construct the index can be found in Section 6.

4 Empirical Strategy

4.1 Baseline Econometric Model

Our study focuses on the effects of early-life iodine deficiency on subsequent human capital attainment in later-life. As we discussed in the previous section, salt iodization was carried out nationwide. Therefore, there is no province that could serve as a pure control group. Similar to Bleakley (2010b) and Adhvaryu et al. (2016), and others, our basic strategy is to use a difference-in-differences design to compare trends in various outcome measures in provinces with different levels of pre-iodization iodine deficiency, where we exploit geographic variation in the prevalence of iodine deficiency prior to the Salt Iodization program. We use the goiter rates among 8-10 years old children in 1995, the year when iodized salt was introduced, to approximate levels of pre-iodization iodine deficiency.

We divide our sample in two groups: those born before and after salt iodization (more precisely, conceived before October 1994 and after October 1994, respectively).[11] The iodized salt campaign was implemented rapidly across the whole country. During the first survey in 1995, more than 80% of families have already access to iodized salt and two year later, in 1997, more than 95% of families have used iodized salt. Our empirical strategy is "sharper" compared to previous studies, which evaluate the salt iodization in the US in the 1920s. There, the salt iodization took several years to cover the entire country and it is not clear which states had access to the new salt earlier.

To study the effects of early-life iodine deficiency exposure, we run regressions of the following form:

$$Y_{ipt} = \beta_0 + \beta_1 Post_t \times Goiter_p + X_{ipt}\rho + \delta_p + \gamma_t + \epsilon_{ipt} \tag{1}$$

where outcome Y_{ipt} is either log cognitive test scores (math and verbal), educational attainment as well as schooling for individual i who was born in province p in year t. $Post_t$ indicates whether the individual was born after the introduction of iodized salt. $Goiter_p$ is a measure of pre-eradication endemicity in individual i's province of birth. δ_p and γ_t are province and birth cohort fixed effects. We also control for region-specific linear trends in all models. The vector X_{ipt} includes individual, family characteristics, a mean-reversion

[10] High goiter provinces are defined by goiter rate higher than 17%.

[11] We use reported date of birth to infer the date of conception as the literature. If there are prematurely born babies, we have measurement error in our birth information and we underestimate the true effects of the intervention. In one robustness check exercise, we drop individuals born between April 1995 and June 1995 and therefore prematurely born babies won't be threats of our identification strategy. More discussion can be found in section 5.

Table 1: Summary Statistics

	High Goiter Provinces		Low Goiter Provinces	
	Pre-policy	Post-policy	Pre-policy	Post-policy
Outcomes				
Educational Attainment	2.95	2.04	3.02	2.06
	[0.84]	[0.82]	[0.78]	[0.84]
Illiterate	0.051	0.29	0.017	0.28
Primary School	0.22	0.41	0.24	0.40
Middle School	0.44	0.27	0.45	0.27
High School or above	0.28	0.039	0.29	0.043
Schooling	9.79	7.21	10.2	7.40
	[3.18]	[2.67]	[2.66]	[2.54]
Math Test Scores	15.2	12.1	15.7	12.4
	[5.73]	[5.27]	[5.19]	[5.00]
Verbal Test Scores	25.8	23.0	26.0	23.4
	[7.44]	[7.60]	[6.73]	[7.20]
Demographics				
Age	18.7	14.4	18.8	14.3
	[2.40]	[2.51]	[2.40]	[2.47]
Father's Education	2.27	2.19	2.50	2.47
	[0.97]	[0.95]	[0.91]	[0.88]
Mother's Education	1.71	1.69	2.07	2.14
	[0.86]	[0.84]	[0.91]	[0.90]
Birth Order	1.59	1.63	1.71	1.67
	[0.80]	[0.80]	[0.88]	[0.94]
Family Size	4.73	4.96	4.78	4.94
	[1.45]	[1.52]	[1.51]	[1.64]
Additional Controls				
No. of hospitals per capita, 0–3 average	15.9	15.7	20.5	18.7
	[5.54]	[4.92]	[12.6]	[10.2]
No. of hospital beds per capita, 0–3 average	21.4	21.3	28.4	27.3
	[3.35]	[3.90]	[11.8]	[10.5]
Gender Attitudes	0.072	0.061	0.13	0.17
	[0.32]	[0.34]	[0.34]	[0.38]
Number of observations	1430	1984	1372	2004

Notes: Author's tabulations of CFPS-2010 and CFPS-2014. Sample consists individuals born in rural area between 1991 and 2000.

control[12] and also province variables such as hospitals and hospital beds per capita. We run specification (1) separately for males and females.

4.2 Dynamic Specification

Since our estimates use the cross-province convergence in goiter rates created by the introduction of iodized salt (Figure 3 and 4), convergent pre-trends across high and low-base goiter rate provinces prior to 1995 are a concern. We use an event study design to try to rule out the existence of differential pre-trends across high and low goiter prevalence provinces (which would indicate a potential violation of our difference-in-difference assumption). More specifically, we run the following regression:

$$Y_{ipt} = \beta_0 + \sum_{t=1991}^{2000} \beta_t \times Goiter_p + X_{ipt} + \delta_p + \gamma_t + \epsilon_{ipt}, \quad (2)$$

where β_t gives the cohort-specific relationship between pre-eradication endemicity and later-life outcomes.[13] If salt iodization affected the human capital formation of exposed cohorts, these effects should be visible in a break from preexisting trends in β_t. This method would also shed light on the partial effects of iodine exposure in late childhood (rather than in utero), if such effects exist.[14] Note that all individuals born in 1995 or later are exposed to iodized salt from conception onward. Individuals born in 1994 experience higher iodine intake in their year of birth; thus, this cohort is partially exposed to better micro-nutrition in utero and fully exposed from birth onward. Individuals born in 1993 experience higher iodine from age 1 onward and those born in 1992 experience higher iodine from age 2 onward. Since we normalize the coefficient for the 1994 cohort to be zero, our analysis essentially tests for differential effects of exposure relative to exposure at age 1 and older. If there are additional benefits to having easy access to iodine between conception and age 1, we would expect the coefficients β_{1995+} to be positive. Similarly, if iodine at age 1 has an additional benefit relative to iodine exposure at age 2 or older, we would expect coefficients β_{1993-} to be negative.

5 Results

5.1 Baseline Results

Table 2 reports the main results of two separate regressions of our basic model (Equation 1): one for men in Panel A and the other for women in Panel B. In all the regressions discussed in this section, the coefficients of interest are the post-by-goiter rate interaction, which represent the effect of salt iodization on our outcomes of interest. To interpret the size of the effect, the coefficients in all tables have been multiplied by 12, which is the inter-quartile range of the goiter distribution from a relatively low goiter province (at the 25th percentile) to a high goiter province (at the 75th percentile). Although the following tables only report the

[12]If the oldest cohorts had high Iodine Deficiency Disorder and low human capital because of some mean-reverting shock, we might expect human capital gains for the subsequent cohorts even in the absence of a direct effect of the new salt on productivity. Follow the similar logic as Bleakley (2010a), we construct the mean-reversion control by interacting provincial average educational attainment in Census 1990 with the dummy variable $Post_t$.

[13]In practice, β_{1994} represents estimates of individuals born between July 1994 and June 1995, and β_{1995} for cohort born between July 1995 and June 1996, etc. We did such adjustments because individuals born after July 1995 were conceived after policy intervention. With some abuse of language, cohort 1993 or individuals born in 1993 actually means born between July 1993 and June 1994.

[14]Zimmermann (2011) gives a comprehensive summary of the role of iodine in human growth at different stages. For example, neonate iodine deficiency would cause endemic cretinism. Deficiency during childhood and adolescence would impair mental functioning and delay physical development.

coefficient of interest, in all specifications we include controls for province and year of birth fixed effects, age, birth order, family size, parents' characteristics and region-specific linear trends. The introduction of new salt took place during a period of rapid growth in economy. To explore these possible confounders, we also control for several characteristics of province of birth (hospitals and hospital beds per capita), measured as averages over the first three years of life. Standard errors are clustered at the province-of-birth level to allow for arbitrary correlation of the errors for individuals born in the same province. For all four human capital measures, we identify significant effects of the intervention for females. A one standard deviation decrease in the pre-intervention goiter rate is associated with a roughly 6% increase in educational attainment as well as a roughly 15% increase in math and verbal test scores. We also see a 12% increase in years of schooling for females. The estimated coefficients using the male sample are consistently smaller in magnitude and not significant.

Table 2: Iodine Exposure and Human Capital Attainment

	(1) Math Test ln(scores)	(2) Verbal Test ln(scores)	(3) Educational Attainment	(4) Schooling ln(years)
Panel A: Males				
Post × Goiter Rate	0.0297	0.0531	0.0216	0.0388
	[0.0761]	[0.0746]	[0.0475]	[0.0604]
Mean of Dep. Var.	**2.46**	**3.05**	**2.41**	**2.02**
Observations	3026	3026	3433	3318
Panel B: Females				
Post × Goiter Rate	0.153	0.136	0.0647	0.124
	[0.0387]***	[0.0565]**	[0.0294]**	[0.0208]***
Mean of Dep. Var.	**2.49**	**3.14**	**2.47**	**2.04**
Observations	2873	2873	3220	3112

Notes: Each coefficient is from a separate regression. All regressions control for fixed effects specific to birth province and birth year, mean-reversion control, age, birth order, family size, parents' characteristics, hospitals per capita, hospital beds per capita and region-specific linear trends. Standard errors clustered by province in parentheses. ∗, ∗∗, ∗∗∗ indicates significance at the 10%, 5% and 1% level respectively.

5.2 Results from the Event Study

Our interpretation of the above coefficients relies on building a causal relationship between the introduction of iodized salt and changes in human capital. If provinces with high and low goiter rates had different pre-intervention trends, however, the effects our models capture may not be due to salt iodization. In order to test for differential pre-trends, we run regressions of the form specified in Equation 2. Figures 5, 6, 7 and 8 present graphical evidence for our event study, where we look at the same dependent variables as in our baseline model. Since we find only significant effects of the iodine intervention for females, we only present graphs for them. Estimates of male sample can be found in Figure B1, B2, B3 and B4 in Appendix B.

First, we can see that for all outcomes, the trends leading up to the intervention are nearly identical for provinces with high and low goiter prevalence. The coefficients for pre-intervention cohorts are close to zero, showing little evidence of an anticipatory response or a pre-trend effect. Estimates of male sample (in

Appendix B) show very similar pattern in pre-intervention estimates. Conditional on a series of controls, above results imply there were no pre-existing trends in the outcomes and therefore supports the common trend assumption in our difference-in-differences design. In Figure 5 and 6, math and verbal scores of females born in the year of the policy intervention increases substantially by 15%, albeit the estimates are slightly noisy and the 95 percent confidence interval of a few cohorts contains zero. In Figure 7 and 8, we see the educational attainment and schooling of females born in the year of the policy intervention increases substantially by 6% and 12%. The lower bounds of the 95 percent confidence intervals are consistently above zero, implying a significant improvement for females born after the intervention year. Females born in later cohorts all obtain comparable benefits from the adoption of the iodized salt. Although the coefficients are not identical across age categories, the 95 percent confidence intervals overlap across all of them. Taken together all evidences from four graphs above imply convincing supports to our key identification assumption, that trends in outcomes between different provinces would have evolved similarly except through the change in the salt iodization policy.

As already mentioned in the previous section, the event study graphs also provide evidence on additional benefits of exposure to iodine between conception and age 1 relative to exposure at age 1 and later. By contrast, the lack of negative coefficients for the cohorts born in 1991 and 1993 suggests that there are little differential benefits from exposure beginning at age 1 or 2. However, because our sample size is quite limited for each cohort, our results on differential benefits from exposure beginning at age 1 or 2 have to be interpreted with caution. With larger data sets, such as census data, researches which could disentangle benefits from exposure beginning at age 1 or 2 would be of great interest to the literature.

5.3 Robustness Analysis

There are a number of reasons why trends in educational outcomes across birth cohorts might differ across provinces. In this section, we explore a number of additional specification checks to make sure our previous estimates can be interpreted as causal effects. The results in Table 3 indicate that our estimates are robust to controlling for birth-region and birth-year specific interaction, using the instrumental variable approach, using raw scores of cognitive tests, and to alternative subsamples. Since we find only significant effects for females, we only present estimates of female sample here.

The first main identifying assumption of the baseline specification is that in the absence of salt iodization there is a common trend across provinces with different levels of goiter rates. As a check, we further control for region of birth by birth year interactions. The results in Panel A are quantitatively similar to our baseline estimates. The impact of introducing iodized salt is even larger after controlling for birth-region and birth-year specific interaction. A one standard deviation decrease in the pre-intervention goiter rate is associated with a roughly 18% increases in cognitive ability and 7-15% in educational outcomes for females.

A second concern is the possible measurement error issue in baseline province-level goiter rates. Although goiter measurements come from a well implemented survey supervised by experts from WHO, the measurement suffer from the timing of the survey is not strictly before the intervention. Although the literature (Zimmermann et al., 2003) has documented a spared lag before the goiter rate normalizes after iodine repletion. To shed light on this concern, we exploit the advantage in our data that province-level iodine contents in water were also collected. As we discussed in previous section, iodine deficiency is linked directly to geography through the food and water supply. Historically, endemic goiter was present in regions where the iodine content of the soil and water was low. The geographic characteristics comparative stable and were determined way before human intervention of iodine supplement. Another source of variability is

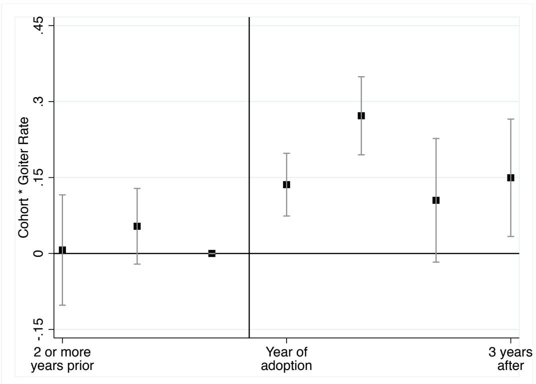


Figure 5. Math Test Scores

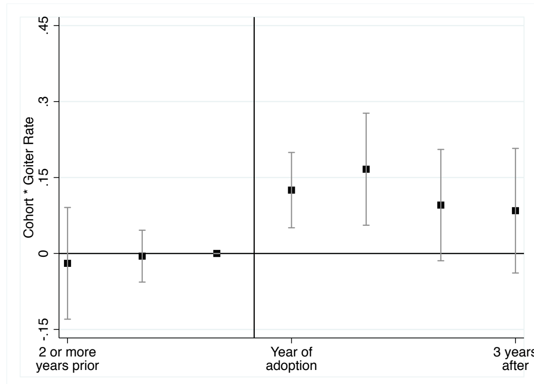


Figure 6. Verbal Test Scores

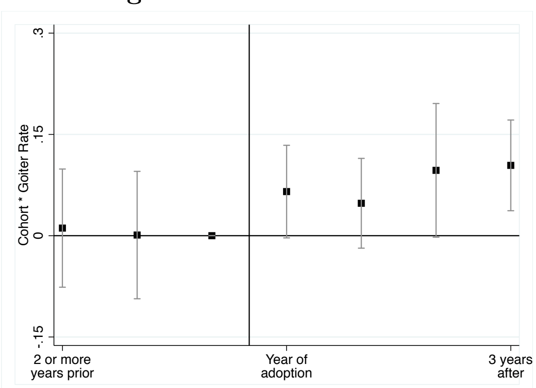


Figure 7. Educational Attainments

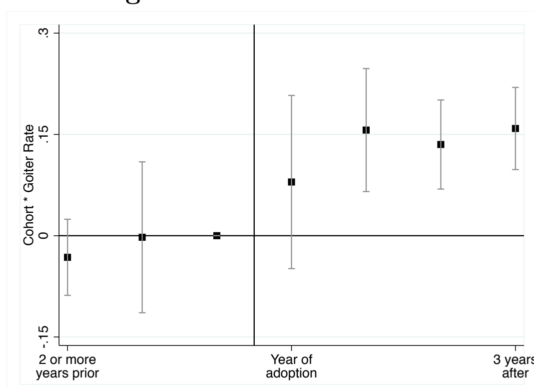


Figure 8. Schooling

Notes: The sample includes all female respondents from three waves of survey. Each point reflects the coefficient estimated on an interaction term between the birth year (compared to 1995) and the pre-intervention (base) level of the goiter rate in the birth-province. Capped spikes represent 95 percent confidence intervals. All models condition upon birth province and birth year fixed effects and the full set of controls used in our main analysis.

Table 3: Robustness Checks (Female)

	(1) Math Test ln(scores)	(2) Verbal Test ln(scores)	(3) Educational Attainment	(4) Schooling ln(years)
Panel A: birth-region and birth-year specific interaction				
Post × Goiter Rate	0.182	0.174	0.0659	0.159
	[0.0467]***	[0.0595]***	[0.0203]***	[0.0318]***
Mean of Dep. Var.	**2.49**	**3.14**	**2.47**	**2.04**
Observations	2873	2873	3220	3112
Panel B: estimates using two-stage least squares				
Post × Goiter Rate	0.213	0.224	0.163	0.233
	[0.0795]**	[0.0855]**	[0.0741]**	[0.0924]**
Mean of Dep. Var.	**2.48**	**3.14**	**2.46**	**2.04**
Observations	2822	2822	3167	3059
Panel C: raw measurements				
Post × Goiter Rate	0.725	0.616	0.0647	0.421
	[0.248]***	[0.417]	[0.0294]**	[0.0676]***
Mean of Dep. Var.	**13.7**	**25.1**	**2.47**	**8.53**
Observations	2873	2873	3220	3112
Panel D: drop partial exposed group				
Post × Goiter Rate	0.132	0.130	0.0521	0.116
	[0.0399]***	[0.0535]**	[0.0299]*	[0.0259]***
Mean of Dep. Var.	**2.48**	**3.14**	**2.47**	**2.04**
Observations	2789	2789	3125	3023
Panel E: only using baseline wave 2010				
Post × Goiter Rate	0.144	0.128	0.0710	0.121
	[0.0356]***	[0.0597]**	[0.0318]**	[0.0319]***
Mean of Dep. Var.	**2.43**	**3.10**	**2.05**	**1.88**
Observations	1726	1726	1771	1771

Notes: Each coefficient is from a separate regression. All regressions control for fixed effects specific to birth province and birth year, mean-reversion control, age, birth order, family size, parents' characteristics, hospitals per capita, hospital beds per capita and region-specific linear trends. Standard errors clustered by province in parentheses. $*$, $**$, $***$ indicates significance at the 10%, 5% and 1% level respectively.

distance from the ocean. As we can notice from Figure 1 and 2, even if a province had a low content of iodine in its drinking water, individual in the coastal province would have have been spared where iodine were enough either in the air or from the sea food. Therefore, the iodine content of drinking water and whether the province is close to the ocean would be two instrumental variables of our main approximation of iodine deficiency (measured by goiter rate) in different provinces. We estimate the same specification using a instrumental variable approach and display the regression results in Panel B. If goiter rates are noisy proxies of iodine deficiency with independent errors, then the measurement-error bias in any one can be corrected by using those two instruments. We found, indeed, the instrumented estimate is higher than the OLS estimate in every case. Results are in the same direction with our main results using only goiter rates which further confirms the causal relation between iodine exposure in utero with later life human capital. However, using iodine contents in water also comes with drawbacks. The national iodine survey only collected a small sample of drinking water to measure the iodine content. In each province, 30-40 samples were gathered, the size of which is much smaller than the sample size when measuring the goiter rate. It is possible that, while the water source in one area was iodine-poor, neighboring areas had access to an iodine-rich supply of water. Albeit problems exist in two approximation of iodine deficiency, our estimates using both OLS and the instrumental variable approach bring comparable results.

The third concern is whether our procedure (take logarithm) of standardizing math and vocabulary ability scores is good enough. Therefore, we run the same regression, but now using raw measurements as the dependent variables. The results in Panel C are roughly the same as those from our baseline models and mitigate our concern of rescaling outcome variables. The interpretation of the results differs so that a one standard deviation decrease in the pre-intervention goiter rate is associated with a roughly 1 point increase in raw test scores for females, the magnitude of which is close to the size of an improvement from a 4-6 months formal school education, which matches the magnitude of our estimates on schooling. In the forth column of Panel C, estimates using raw schooling measurements (years) imply an estimated 0.5 years of additional schooling for females.

In a further robustness check, we drop individuals who were partially exposed to iodine in their first trimester from our main sample.[15] Our key identification strategy is to exploit the impact of differential in utero exposure to iodine specifically in the first trimester, since the literature has documented the important role of iodine to the central nervous system. Individuals born in June 1995, for example, were exposed to additional iodine from salt from the second month in utero. Additionally, we use reported date of birth to infer the date of conception as the literature. If there are no prematurely born babies, we have measurement error issues that could bias our estimates. Our current exercises help us to address both issues mentioned above. Panel D reports the results using the subsample after dropping individuals born between April 1995 and June 1995. We do not see significant differences in the estimates when we use this subsample. And we can notice that coefficients are indeed slightly larger, which gives us further confidence on the causal relation we documented.

The last robustness check addresses the concern that performance on the test in the wave 2014 may reflect learning how to take this specific version of the test. In our basic specification, we pool samples from two waves to fully utilize the comparable tests that were administered in different years. The advantage of pooling is that we can control for age in the regressions. The individuals in our analysis are in their early-adulthood where math and verbal ability is strongly related to age when taking tests. Controlling for age increases

[15] Those individuals were in post-intervention group in my baseline model. Therefore our baseline model underestimate the true effects.

the precision of our estimates. The downside of using information from all waves is that individuals might learn from the test results in the first wave, which makes the test scores in the second wave inappropriate measurements of human capital development. As a check, we run regressions using only the data from the first wave of the CFPS.[16] However, we now not only cannot control for age in our regression, but also lose half of the sample. Nonetheless, the results in Panel E are consistent with the ones from our benchmark model, which further reinforces our main findings on the causal relation between iodine in utero and human capital development. We also carry the same event study design as before but now only using data from the first wave (CFPS-2010). The results are displayed in Figure B5, B6, B7 and B8. Similarly, we can see very clear trend break at the intervention year and we don't see any pre-existing trends in the outcomes. All the evidence above implies that iodine in utero has critical impacts in human cognitive development and disadvantage at early-life generate inequality in the process of human capital formation.

Finally, we further verify our identification assumptions and demonstrate the statistical power of the inferences using our baseline specification by conducting falsification tests, where we assign a pseudo-treatment. More precisely, we randomly assign province of birth and thus pre-intervention goiter rates to each respondents in our sample. If our identification strategy is indeed valid, we would expect estimates using those pseudo-sample were centered around zero. We can then compare the estimates using the true sample with the distribution of effects that we estimate from randomly generated pseudo-samples.

In Figures 9, 10, 11 and 12, we plot the distribution of t-statistics from 5,000 estimated pseudo-treatment effects on educational attainments, schooling, math and verbal ability, respectively. As expected, all four distributions are centered around zero. Taking together, these results imply that assumptions in our empirical model are unlikely be be severely violated. To access the statistical power of our model, we mark within the pseudo-treatment effect distribution the location of the t-statistic of the corresponding treatment effect using the actual pre-intervention goiter rate. We also report the share (p-value) of the pseudo-treatment t-statistics that is larger than the actual t-statistic in absolute value. From the graph, "p-value" from the inferences based on the pseudo-treatments are similar to what we find in previous baseline regressions.

5.4 Comparison to Other Cohort-Based Studies

Several other recent studies (Field, Robles, and Torero, 2009; Adhvaryu et al., 2016; Feyrer, Politi, and Weil, 2017) also analyze the intermediate or long-run impacts of the iodine deficiency in early-life by leveraging either historical information of introducing the iodized salt in developed countries or recent iodine supplementation programs in Africa. Methodologies used in the literature are generally similar to the ones we employed here, and therefore we can compare and contrast their results with ours.

Particularly, Adhvaryu et al. (2016); Feyrer, Politi, and Weil (2017) both study a similar policy in the U.S. in the 1920s. Their research design is also the difference-in-differences models. A big advantage of above two studies over the current study is that they can evaluate long-run outcomes such as income as well as labor force participation. According to the analysis in Bleakley (2010a), educational attainments, particularly years of schooling, is not idea when the interests is to measure the impact of early-life health on lifetime income.[17] However, the disadvantages of these studies relative to this one are two-fold. First, they measure goiter prevalence using information from military recruits, where the index population to measure

[16] This also speaks to the attrition issue of our survey data. Second wave lost around 30% percent of observations due to attrition. Results only using the first wave show similar results and give us confidences that our findings were not driven by selection problem.

[17] Schooling might decrease if positive health shock drive down marginal costs (including opportunity costs) of education more than the marginal benefits of education, while the lifetime income can still benefit from the health improvement.

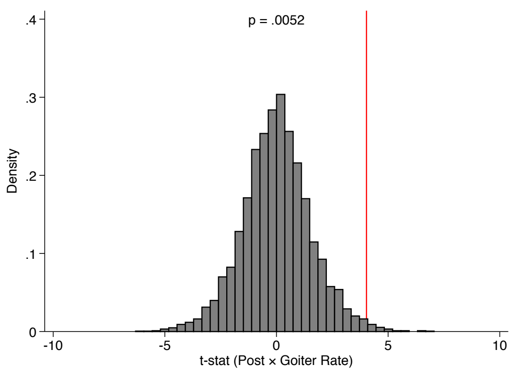


Figure 9. Math Test Scores

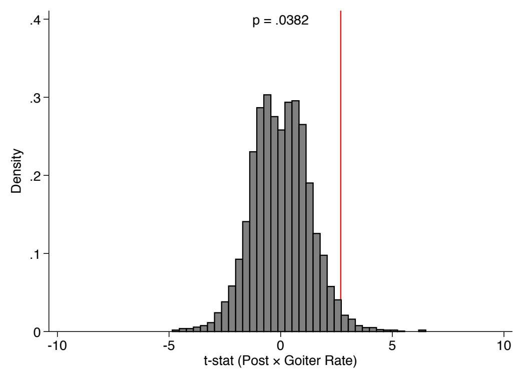


Figure 10. Verbal Test Scores

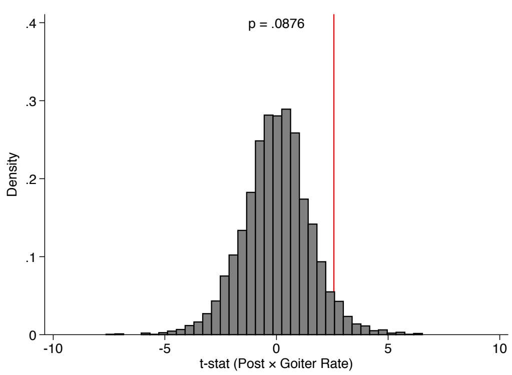


Figure 11. Educational Attainments

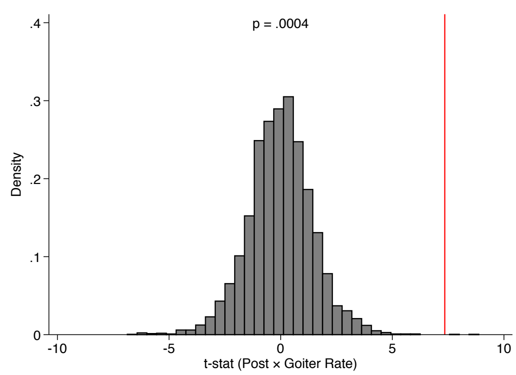


Figure 12. Schooling

Notes: Pseudo-treatment vs. actual policy intervention: the distribution of t-statistics resulting from 5,000 random assignments of treatment to individuals, as well as the t-statistics from the actual treatment through the policy intervention (red line). "p-values" report the share of the pseudo-treatment t-statistics that is larger than the actual t-statistics.

goiter rates are usually young healthy men. Thus, their goiter prevalence information might be subject to bigger measurement error. Second, although the introduction of iodized salt across the US was rapid, not every state accessed to the new salt at the same time. Additionally, they don't have the accurate timing and precise geographic information of this nationwide spread. Thus, plausible endogenous coverage among different states of the new salt might bias their difference-in-differences estimates.

To the best of my knowledge, Field, Robles, and Torero (2009) is the first economic study on the long-run effects of iodine deficiency in early-life. The study uses a slight different research design, i.e. family fixed effects models. The analyses of Tanzania data provide the first micro-level evidence of the influence of iodine availability in utero on cognition development of girls. However, one threat to the research design is that other aspects of the iodine supplementation program (e.g., health information) might also have effects on human capital development of children. Another disadvantage of the study comes from the only measurement of the human capital i.e., grade attainment. As we have discussed before, educational attainments such as schooling is not a sufficient statistics of human capital. In our studies, we instead look at a battery of human capital measurements, among which math ability has been documented to be strongly correlated with the lifetime income (Joensen and Nielsen, 2009; Chetty et al., 2011; Fredriksson, Öckert, and Oosterbeek, 2012). Therefore, our results using ability test scores contribute to the literature and create a more integrated picture of human capital gain through an early-life iodine intervention.

The literature has explored different policy variations in different countries, while all findings are particularly consistent with each other. All analysis find strong effects of iodine in utero for female, which is also consistent with the medical literature that female fetuses are more sensitive to maternal thyroid deficiency than male fetuses. All the evidences imply that female benefit from this public health intervention would also perform better in labor market and therefore have higher income in the near future. Further studies looking in to the long-run impacts on income of such intervention in different contexts would be also be of great interest.

5.5 Putting the Magnitude into Context

Our study has documented a roughly 15% increase in cognitive ability among female for a one standard deviation reduction in goiter rates results. The size of the effects is also comparable to the effects documented in Adhvaryu et al. (2016). They find effects of salt iodization on labor supply and income, which seem to be entirely driven by the large impact salt iodization had on women early in their careers. The similarity of estimates using data sets from different countries with different characteristics speaks to the external validity of our current study and further supports the effectiveness of such an important public health intervention. Based on their studies about Tanzania, Field, Robles, and Torero (2009) predict that the Universal Salt Iodization (USI) campaign would enhance schooling ranging from 0.5 percent to 40 percent for different countries, among which 13 countries should experience more than a 10 percent improvement. Our estimates have similar magnitudes with their study and therefore provide some new supporting evidences for their prediction.

Our estimates have documented significant effects of the iodine intervention on human capital formation for females. The magnitude is close to what have seen in the literature looking at similar policies but in different countries. Taken together the evidences from all these studies imply that the intervention would boost females' human capital and income by around 10%. Comparing to other interventions to raise education, the cost of such intervention is extremely low. Acutely, in U.S., the fortification was totally promoted by a private firm, Molton Salt. In China, the production of the salt is regulated by state own firms. But in both cases, the cost of such intervention is very low, that is about 0.05$ per person per year according to a calculation in 2005 by WHO. While intervention by reducing class sizes, for example, (Chetty et al., 2011) cost over $5,000 (2010 dollars) per year per student. One of the reason that the intervention at early life is particularly effective is the importance of nutrition in critical periods. The adverse effects of iodine deficiency in utero are especially severe, that nuclear thyroid hormone receptors are present in the fetal brain by nine weeks (mainly the first trimester). The second reason has already been pointed out in Heckman (2007) that 'capabilities beget capabilities'. Better cognitive capacity at early-life make the following investments more effective.

6 Gender Differences in Policy Impacts

6.1 Conceptual Framework

As mentioned in the previous section, our analysis only finds significant effects for girls. The literature often attributes this gender difference to the well documented biological mechanism that female fetuses are more sensitive. However, a more compelling explanation for the gender difference in the impact of iodized salt is that parental investment mitigates or amplifies early-life disadvantages. This question connects to a small but growing literature looking at how inputs/shocks at different stages of life interact with each other, i.e. the dynamic complementarities (see Cunha et al., 2006; Cunha, Heckman, and Schennach, 2010) of human capital formation. If such complementarities exist, then early human capital investments can make subsequent human capital investments more productive. Despite the importance for policy makers, very little quasi-experimental research[18] looks into how effective policies, that promote human capital in early life, are affected by policies that promote human capital accumulation later in life and vice versa. We contribute to this strand of the literature by interacting variation in human capital investments with the shock (the introduction of iodized salt) that promotes human capital in early life.

Ideally, we would analyze the heterogenous effects of iodized salt under different levels of parental investment. However, our data sets do not contain sufficient information on parents' investment in our target sample.[19] Therefore, we instead exploit variation in parental investment driven by differential parental son preferences. Gender gaps favoring males - in education, health, personal autonomy, and more - are larger in poor countries than in rich countries and are particularly profound in Asian countries like China and India. A large literature has tried to document discrimination towards girls in parental investment. Boys in families with a strong preference for sons obtain higher investments as measured by vaccination rates (Oster, 2009), breastfeeding behavior (Jayachandran and Kuziemko, 2011), and parental time allocation (Barcellos, Carvalho, and Lleras-Muney, 2014). The literature also documents that those inputs from parents can have a significant impact on important outcomes such as height and cognitive development of children. However, an unanswered question in this literature is whether those differences in parental investments driven by son preferences mitigate or reinforce early life disadvantages. Our study bridges the two strands of the literature, "fetal origin" and "son preferences", by looking at the heterogenous treatment effects of the intervention across families with different gender preferences.

Similar to Dhar, Jain, and Jayachandran (2015) and Dahl, Kotsadam, and Rooth (2017), we measure

[18]See (Adhvaryu et al., 2015; Malamud, Pop-Eleches, and Urquiola, 2016; Gunnsteinsson et al., 2016; Duque, Rosales-Rueda, and Sanchez, 2017) for example.

[19]The questions in the CFPS about parental investment were targeted at children aged between 5 to 12. However, we have limited evidences on the relation between gender attitudes and parental investment (available upon request).

Table 4: Summary Statistics of Gender Attitudes

	Male	Female
Preferences		
Son should live together with parents.	3.50	3.51
	[1.34]	[1.38]
Every family should at least have a son.	3.48	3.42
	[1.48]	[1.54]
Husband takes care of the business, wife takes care of the family.	4.11	4.13
	[1.09]	[1.12]
Woman's marriage is more improtant than her career.	3.50	3.79
	[1.33]	[1.26]
Every woman should have a child.	4.07	4.35
	[1.17]	[1.02]
Disagree: Husband should do half of the housework.	1.94	1.84
	[1.09]	[1.05]
Indexes		
Unweighted gender index	3.43	3.50
	[0.69]	[0.70]
Weighted gender index	-0.039	0.037
	[1.00]	[1.00]
Number of observations	8542	8496

Notes: Sample includes all individuals aged between 30 and 50 in CFPS-2014. Surveyed respondents were asked if they agree with these six statements. The respondents report how much they agreed with a certain statement on a scale of 1-5, with 1 being *Strongly agree* and 5 being *Strongly disagree*. Unweighted Gender index is the average of the 6 indicators. Weighted gender index is the weighted average value of the same 6 categorical variables, with weights constructed by normalizing the variables to have the same standard deviation and then recovering the weights given by the inverse covariance matrix (Anderson (2008)).

son preferences by gender attitudes, i.e. the appropriate roles and rights of women and girls. The CFPS-2014 includes a number of questions on gender equity attitudes answered by all respondents, covering topics such as gender roles within the household and in public life and whether girls and boys should have equal educational opportunities. We create a gender index that aggregates the responses for the six questions listed in Table 4. Surveyed respondents were asked if they agree with these six statements on a scale of 1 to 5, with 1 being "Strongly agree" and 5 being "Strongly disagree", whereby the statement was phrased in favor of gender equality and female empowerment. For each respondent of the survey, the gender attitudes index is the weighted average value of the six categorical variables and a lower gender index means more gender equitable views. Weights are constructed by normalizing the variables to have the same standard deviation and then recovering the weights given by the inverse covariance matrix (Anderson, 2008).

6.2 Results

Specifically, we estimate the following equation by gender:

$$Y_{ipt} = \beta_0 + \beta_1 P_t \times G_p \times GA_i + \beta_2 P_t \times G_p + \beta_3 P_t \times GA_i + \beta_4 GA_i + X_{ipt}\rho + \delta_p + \gamma_t + \epsilon_{ipt} \quad (3)$$

where GA_i refers to measurements of gender attitudes in village/community that the individual lives in. We aggregate gender attitudes at the living village/community level. We calculate the mean gender attitude of individuals aged between 30 and 50 (approximately the same age as the parents of our target sample) for each village/community, and merge it to our analysis sample in the corresponding village/community. In the Appendix C, we leave the parents of our sampled individuals out when we calculate the mean. Parents' gender attitudes might be affected by the intervention, which has reduced the gender gap substantially according to our analysis.

β_1 is the main coefficient of interest, capturing the differential effect of the iodine fortification program across families with various levels of son preferences. In other verbals, β_1 indicates to what extent parental investments mitigate the disadvantage early in life. Building on our previous DID strategy to identify the causal effects of the new salt, our analysis is also conditioning on province of residence fixed effects. Therefore, our empirical specification absorbs differences in actual cognitive ability across the province. By conditioning on birth cohort fixed effects, we also absorb all variation across age groups. We also include X_{ipt} to control for individual, family and provincial characteristics analogously to our main analysis.

Table 5 reports the results by gender, where GA is aggregated at the village/community level. For females, the estimates show that compared to individuals born in areas with more equal gender attitudes, individuals born in areas with stronger son preferences benefit more from the policy. In other words, the shock from iodized salt benefits females who received lower parental investments more. The large magnitudes of the interaction terms in all regressions suggest a large potential for parental investments to remedy inequalities in endowments. Except the only significant coefficient for the estimate of educational attainment, we didn't find gradients by gender attitudes for males, which suggests the hypothesis that males obtain in general higher investments from their families and early-life inequality therefore was mitigated.[20] We find little evidence of dynamic complementarities. However, as discussed by Malamud, Pop-Eleches, and Urquiola (2016), our estimates are not a test sufficient to allow us to reject the presence of dynamic complementarities. We only estimate reduced-form interactions between an early life intervention and investment differences driven by

[20] However, we can't rule out an alternative explanation that males are not affected by iodine deficiency at all. So the iodine policy has no effect, no matter whether boys received high or low parental investments.

Table 5: Gradients in Long Run Impacts of Iodine Exposure by Gender Attitudes

	(1) Math Test ln(scores)	(2) Verbal Test ln(scores)	(3) Educational Attainment	(4) Schooling ln(years)
Panel A: Males				
Post × Goiter Rate × Gender Attitudes	-0.0157	-0.0809	-0.148	0.0735
	[0.134]	[0.133]	[0.0569]**	[0.194]
Post × Gender Attitudes	0.0175	0.176	0.253	-0.00240
	[0.278]	[0.286]	[0.141]*	[0.241]
Post × Goiter Rate	0.0500	0.0948	0.0557	0.0789
	[0.0581]	[0.0438]**	[0.0451]	[0.0406]*
Mean of Dep. Var.	**2.46**	**3.05**	**2.37**	**2.03**
Observations	2784	2784	2908	2860
Panel B: Females				
Post × Goiter Rate × Gender Attitudes	0.371	0.282	0.0968	0.286
	[0.146]**	[0.171]	[0.0367]**	[0.120]**
Post × Gender Attitudes	-0.511	-0.418	-0.0744	-0.330
	[0.254]*	[0.209]*	[0.0846]	[0.118]***
Post × Goiter Rate	0.0875	0.0953	0.0395	0.0885
	[0.0391]**	[0.0488]*	[0.0329]	[0.0273]***
Mean of Dep. Var.	**2.49**	**3.14**	**2.43**	**2.04**
Observations	2631	2631	2745	2713

Notes: Each coefficient is from a separate regression. All regressions control for fixed effects specific to birth province and birth year, mean-reversion control, age, birth order, family size, parents' characteristics, hospitals per capita, hospital beds per capita and region-specific linear trends. Standard errors clustered by province in parentheses. $*$, $**$, $***$ indicates significance at the 10%, 5% and 1% level respectively.

son preferences. The reduced-form estimates do not allow us to disentangle endogenous responses within households, because parents may deliberately choose the human capital investments they direct towards their children. For instance, their investments (given their son preferences) may respond to their children's endowments (Adhvaryu and Nyshadham, 2016). However, given the limited information about parental investment in our data sets, it is still an open question whether parents deliberately choose investments for individuals with different endowments.

7 Conclusion

In this study, we document the effects of adopting Universal Salt Iodization (USI) in China. A one standard deviation decrease in the pre-intervention child goiter rate is associated with math and vocabulary scores increasing by roughly 15%. We also see large increases in the educational attainment of girls. Yet, we do not find significant effects for boys, which is consistent with the literature. We find females born in districts with a stronger preference for sons attain larger improvements in human capital after the introduction of the iodized salt. Such heterogenous effects of the iodized salt support the hypothesis that parents' investment can partly mitigate the early-life disadvantage.

Our study evaluate the long-run impacts of an important global public health policy campaign initialed by the World Health Organization (WHO). Combined with historical evidences from U.S. and Switzerland, we bring together the full picture of how intervention on nutrition shape the inequality in human capital development at childhood and then further have impacts on adults earning. We see not only the schooling but also math and vocabulary ability were boosted by improving nutrition in the early-life. Our evidences at childhood is consistent with adults evidences from other studies that females born after the intervention have higher labor force participation, income or a higher probability to enter top-tier occupations with higher cognitive demands. For other researches with a similar design, measurements of human capital such as math and vocabulary ability in childhood could play the role of surrogates when long-term outcomes were yet unobserved. Both empirical and theoretical researches in this direction would be very important for the researchers and policy maker (see Athey et al., 2016, for a formal framework about surrogates). We also find that parental gender attitudes interact with early-life shocks in the Asia context, which supports the importance of parental investment. Studies carefully looking into the black box of the human capital formation, particularly about the role of parental investments, would also be of great interest to the literature.

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Appendix A Additional Tables

Table A1: Summary Statistics for Female

	High Goiter Provinces		Low Goiter Provinces	
	Pre-policy	Post-policy	Pre-policy	Post-policy
Outcomes				
Educational Attainment	2.96	2.08	3.11	2.09
	[0.84]	[0.83]	[0.76]	[0.85]
Illiterate	0.048	0.26	0.016	0.28
Primary School	0.22	0.42	0.19	0.38
Middle School	0.44	0.27	0.46	0.29
High School or above	0.29	0.049	0.33	0.045
Schooling	9.87	7.34	10.4	7.47
	[3.15]	[2.73]	[2.61]	[2.62]
Math Test Scores	15.2	12.2	16.2	12.6
	[5.64]	[5.23]	[4.88]	[5.19]
Verbal Test Scores	26.3	23.9	26.9	24.2
	[7.24]	[7.28]	[5.90]	[7.01]
Demographics				
Age	18.6	14.5	18.8	14.3
	[2.39]	[2.52]	[2.39]	[2.47]
Father's Education	2.29	2.19	2.51	2.46
	[0.95]	[0.94]	[0.93]	[0.87]
Mother's Education	1.68	1.68	2.13	2.16
	[0.85]	[0.85]	[0.92]	[0.92]
Birth Order	1.60	1.56	1.60	1.62
	[0.84]	[0.73]	[0.79]	[0.95]
Family Size	4.86	5.13	4.89	5.10
	[1.47]	[1.57]	[1.47]	[1.67]
Additional Controls				
No. of hospitals per capita, 0–3 average	15.9	15.6	20.8	19.0
	[5.23]	[4.96]	[12.7]	[10.3]
No. of hospital beds per capita, 0–3 average	21.6	21.2	28.6	27.8
	[3.52]	[3.62]	[11.8]	[10.9]
Gender Attitudes	0.063	0.049	0.11	0.17
	[0.30]	[0.37]	[0.34]	[0.39]
Number of observations	681	956	644	997

Notes: Author's tabulations of CFPS-2010 and CFPS-2014. Sample consists individuals born in rural area between 1991 and 2000.

Table A2: Regional Classification of Provinces

Region	Provinces
North China	Beijing, Tianjin, Hebei, Shanxi and Inner Mongolia
Northeast China	Liaoning, Jilin and Heilongjiang
East China	Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi and Shandong
South Central China	Henan, Hubei, Hunan, Guangdong, Guangxi and Hainan
Southwest China	Chongqing, Sichuan, Guizhou, Yunnan and Tibet
Northwest China	Shaanxi, Gansu, Qinghai, Ningxia and Xinjiang

Appendix B Robustness

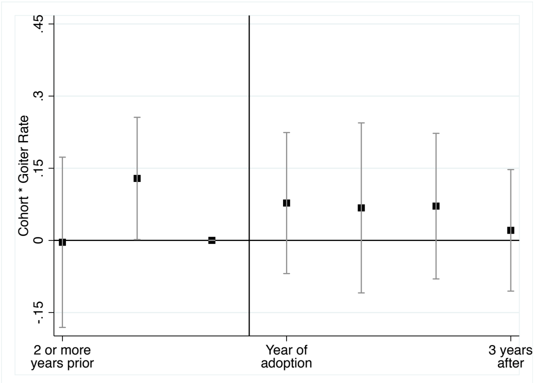

Figure B1. Math Test Scores

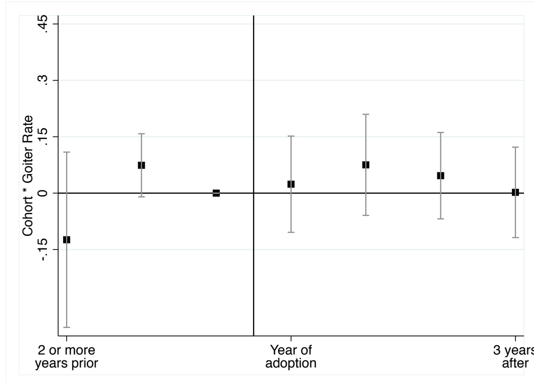

Figure B2. Verbal Test Scores

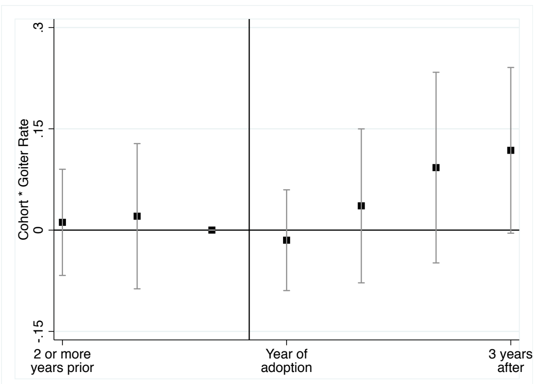

Figure B3. Educational Attainments

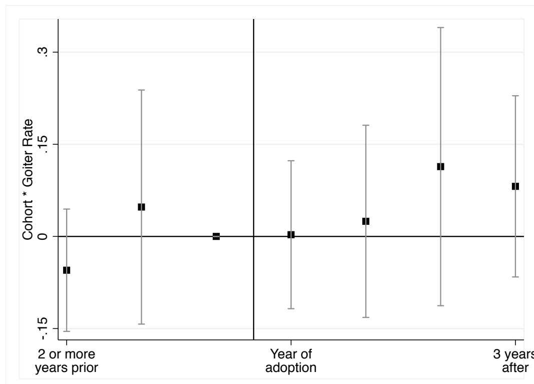

Figure B4. Schooling

Notes: The sample includes all female respondents from three waves of survey. Each point reflects the coefficient estimated on an interaction term between the birth year (compared to 1995) and the pre-intervention (base) level of the goiter rate in the birth-province. Capped spikes represent 95 percent confidence intervals. All models condition upon birth province and birth year fixed effects and the full set of controls used in our main analysis.

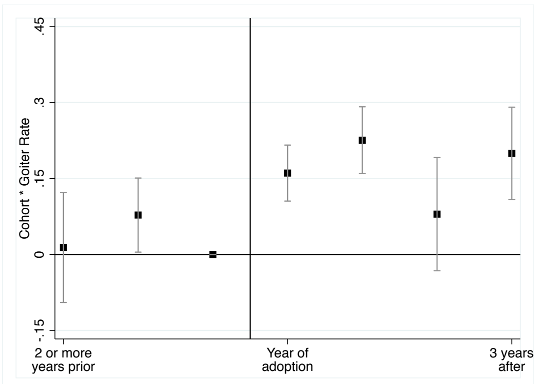

Figure B5. Math Test Scores

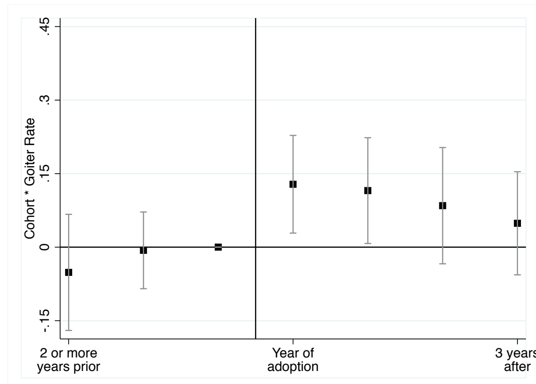

Figure B6. Verbal Test Scores

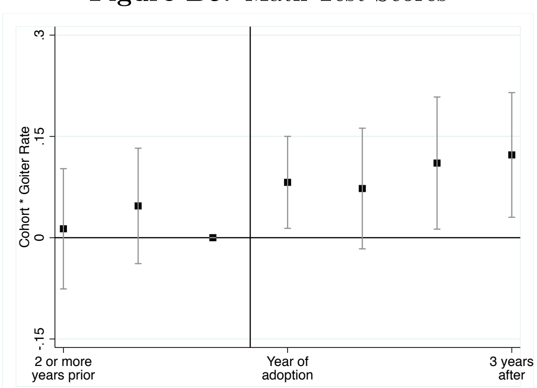

Figure B7. Educational Attainments

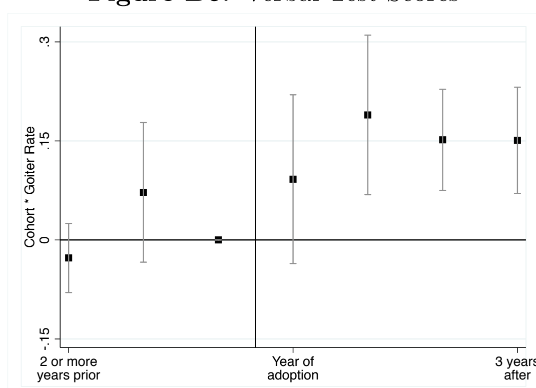

Figure B8. Schooling

Notes: The sample includes all female respondents from three waves of survey. Each point reflects the coefficient estimated on an interaction term between the birth year (compared to 1995) and the pre-intervention (base) level of the goiter rate in the birth-province. Capped spikes represent 95 percent confidence intervals. All models condition upon birth province and birth year fixed effects and the full set of controls used in our main analysis.

Appendix C Gender Attitudes

Table C1: Robustness on Gender Attitudes

	(1) Math Test ln(scores)	(2) Verbal Test ln(scores)	(3) Educational Attainment	(4) Schooling ln(years)
Panel A: Males				
Post × Goiter Rate × Gender Attitudes	-0.0176	-0.0417	-0.0892	0.0807
	[0.146]	[0.145]	[0.0443]*	[0.179]
Post × Gender Attitudes	0.0793	0.168	0.191	-0.00101
	[0.320]	[0.300]	[0.113]	[0.213]
Post × Goiter Rate	0.0514	0.0870	0.0447	0.0744
	[0.0538]	[0.0388]**	[0.0451]	[0.0384]*
Mean of Dep. Var.	**2.46**	**3.05**	**2.37**	**2.03**
Observations	2753	2753	2877	2830
Panel B: Females				
Post × Goiter Rate × Gender Attitudes	0.277	0.254	0.0515	0.218
	[0.113]**	[0.155]	[0.0349]	[0.0958]**
Post × Gender Attitudes	-0.314	-0.355	0.0676	-0.189
	[0.193]	[0.196]*	[0.0588]	[0.0988]*
Post × Goiter Rate	0.0973	0.0977	0.0474	0.0977
	[0.0395]**	[0.0517]*	[0.0336]	[0.0253]***
Mean of Dep. Var.	**2.49**	**3.14**	**2.42**	**2.03**
Observations	2609	2609	2720	2689

Notes: Each coefficient is from a separate regression. All regressions control for fixed effects specific to birth province and birth year, mean-reversion control, age, birth order, family size, parents' characteristics, hospitals per capita, hospital beds per capita and region-specific linear trends. Standard errors clustered by province in parentheses. $*$, $**$, $***$ indicates significance at the 10%, 5% and 1% level respectively.