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Farewell to the God of Plague: Estimating the effects of China's Universal Salt Iodization on educational outcomes

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ABSTRACT

This paper estimates the effects of China's Universal Salt Iodization (USI) policy in 1994 – the largest nutrition intervention policy in human history – on children's later-life educational outcomes. Using population census data combined with county-level information, we apply a difference-in-differences strategy to compare the educational outcomes of cohorts born before and after USI across counties with different iodine deficiency disorder levels. Our results show that USI increased primary school enrollment by 0.6 percentage points. Further investigation suggests that girls and children born in rural areas benefit more from USI. The costs of USI almost evenly fell on China's iodine salt consumers through an in-price tax.

1. Introduction

Scholars have long recognized a deficiency in the consumption of essential micronutrients as a primary impediment of health and human capital formation. Among various types of micronutrient deficiencies, iodine deficiency disorder (henceforth, IDD) has been the leading cause of preventable mental retardation (Ahmed, 2008).[1] Iodine deficiency *in utero* has irreversible detrimental impacts on the development of the infant nervous system, which ultimately limits the development of cognitive ability and hinders human capital formation.[2] There is substantial scientific evidence that the critical determinant of IDD prevalence is the iodine content in food and drinking water from which iodine intake is almost entirely derived (Murray et al., 2008). Iodine content in soil and water differs widely across localities as a result of the geological transformation between the sea and continental areas in ancient geological times.

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[1] Iodine is a key component of thyroid hormone, which is essential for metabolism. An adult requires about 60 μg of iodine per day to maintain the synthesis of thyroid hormone (Zimmermann, Jooste, and Pandavand, 2008). When iodine intake is insufficient, the secretion of TSH (thyroid-stimulating hormone) increases to produce thyroxin at higher efficiency, leading to the enlargement of the thyroid (i.e. goiter), which is a traditional signal of IDD.

[2] A large body of biological and medical literature has demonstrated that fetuses in the middle and late periods of utero are most vulnerable to iodine deficiency (Cao et al., 1994). Even mild or moderate iodine deficiency *in utero* will lead to lifelong cognitive impairment at varying degrees.

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Therefore, IDD is a typical endemic disease.[3] According to a World Health Organization (WHO) report, nearly two billion people throughout the world live in iodine-deficient areas, a third of which are of school age (World Health Organization, 2007). WHO recommends universal salt iodization (USI) as the cheapest and most efficient way to prevent IDD, especially for developing countries with large populations living in iodine-deficient areas.

wThis paper estimates the effect of China's USI policy – the largest nutrition intervention policy in human history – on children's later-life educational outcomes. China had over 700 million people living in areas suffering from IDD in the early 1990s. To eliminate IDD by 2000, the Chinese government initiated a USI policy on October 1, 1994, which mandated the iodization of edible salt throughout the country. Using China's 2005 population mini-census data combined with county-level information, we apply a difference-in-differences (DID) strategy which compares the outcomes of children born before and after the USI policy in 1994 across counties with different IDD prevalence levels. We find that the USI policy significantly increases primary school enrollment for the policy-affected cohorts in high goiter counties by 0.6 percentage points.[4] The costs of USI almost evenly fell on the iodized salt consumers through an in-price tax levied by China's central government. Therefore, our findings yield clear redistribution implications.

China's USI policy serves as an ideal natural experiment to examine the causal effects of salt iodization for two reasons. First, a state monopoly on salt in China ensured strict nationwide enforcement of USI and ruled out the potential endogeneity of producing or consuming iodized salt, which may threaten a causal analysis of the policy effect. China instituted state monopolization of salt production, distribution, and sales beginning in 1990. Specifically, China's central government authorized China Salt Industry Corporation, a central state-owned enterprise, other local state-owned enterprises in the salt industry, and local branches of these enterprises throughout the country to monopolize the production, distribution, and sales of edible salt. Second, before the enactment of USI, China had the largest population in the world exposed to IDD and exhibited rich regional heterogeneity in IDD levels. The Chinese government conducted an iodine deficiency census in the 1980s, which furnishes us with a comprehensive dataset with rich county-level information, including IDD prevalence and water iodine content.

Our DID analysis is built on a solid analytical foundation. We find that there are no differential pre-trends of primary school enrollment across counties with different goiter prevalence rates. Our results are highly robust to a full battery of robustness checks and falsification tests. We use county-level water iodine content as an instrumental variable to deal with potential measurement error and nonrandomness in the spatial distribution of IDD prevalence. Although we have no direct measure of children's cognitive ability to certify the mechanism, we provide evidence that the USI policy does not work through improving children's physical health.

The effect of the USI policy on primary school enrollment in China is heterogeneous across several important soci-oeconomic dimensions. We find that the USI policy effect almost exclusively shows up in rural areas rather than in urban areas with much better access to alternative ways of overcoming IDD (e.g., through seafood consumption) and girls benefit more from the USI policy. These findings forcefully suggest that the USI policy is desirable not only on efficiency terms but also on social justice grounds.

To the best of our knowledge, we are among the first empirical studies to investigate the causal effect of China's nationwide USI intervention on educational outcomes. In terms of research theme, this paper contributes to a growing body of scholarship evaluating the effects of various types of early-life micronutrient supplements on later-life outcomes, such as iron (Bobonis et al., 2006; Chong et al., 2016; Banerjee et al., 2018) and iodine (Field et al., 2009; Politi, 2014; Feyrer et al., 2017; Adhvaryu et al., 2019; Bengtsson et al., 2019). This paper is not the first research to examine the effects of the eradication of iodine deficiency disorders on educational outcomes. In a pioneering work, Field et al. (2009) gage a magnitude of 0.35–0.56 years of additional years of schooling for children treated *in utero* with iodine oil through an iodine supplementation policy in Tanzania. However, a replication work by Bengtsson et al. (2019) fail to establish a significant positive effect on educational attainment even when they use a larger sample and improve the precision of the treatment variable. Taking advantage of Switzerland's iodized salt introduction campaign, Politi (2014) documents a one percentage point increase in the secondary school graduation rate and a 0.7 percentage point increase in the tertiary school graduation rate. Motivated by another historical natural experiment, the fast salt iodization campaign in the United States in 1924, Feyrer et al. (2017) find that this campaign had a significant effect on intelligence quotient when delving deeply into a unique dataset compiled from draft physicals for American army enlistees during World War I and World War II. Adhvaryu et al. (2019)'s analysis builds on the same historical natural experiment and provides evidence of considerable effects on labor force participation and income. However, the effect they find is smaller and insignificant in the subsample of males. In a word, reliable causal evidence, especially evidence from developing countries, is still inadequate to forcefully argue that large-scale salt iodization intervention causally improves educational outcomes. A formal empirical investigation into China's USI policy is itself of vital importance since it has a long-lasting impact on over 20% of the world's population. Our finding also serves as a counterweight to recent clamor and advocacy in China for abolishing USI.[5] Since most people might be unconscious of or underrate potential gains from micronutrient supplementation, policymakers should be cautious in handling this issue of important policy relevance.

Our study is closely related to a large and expanding literature on *Fetal Origins Hypothesis* (FOH), which examines the short- and long-term effects of specific factors *in utero* on later-life outcomes.[6] The recent FOH literature exhibits an increasing interest in

[3] According to Dicker et al. (2006), "Endemic refers to the constant presence and/or usual prevalence of a disease or infectious agent in a population within a geographic area."

[4] According to official policy criterion, if a county's goiter prevalence rate surpassed 3%, it is defined as a high goiter county. Source: *The Interim Rules for Prevention and Treatment of Endemic Goiter by Salt Iodization* (*Shiyan jiadian fangzhi dian quefa bing zanxing banfa*), was enacted by the Ministry of Health on December 21, 1979.

[5] See http://epaper.bjnews.com.cn/html/2014-10/20/content_541739.htm?div=-1 for a case in the news.

[6] See Almond and Currie (2011) and Almond et al. (2018) for excellent literature reviews.

examining the effects of positive policy-driven *in utero* interventions on later-life outcomes (Bharadwaj et al., 2013; Almond et al., 2018; Nilsson, 2017). Researchers and policy-makers are especially eager to know whether some intervention policy tools derived from well-established causal evidence in scientific laboratory experiments or randomized controlled trials deliver their anticipated results when scaled up and implemented through government policies.[7] We contribute to this literature by investigating the causal effects of a nationwide health policy intervention in China on the early cognitive development of children (indirectly measured by educational outcomes).

Finally, our research speaks to a hotly debated issue about the role of geographic factors in shaping regional income disparities (Diamond, 1997; Sachs, 2003; Nunn and Puga, 2012; Henderson et al., 2017). Endemic diseases play a crucial role in translating geographic factors into human capital accumulation and regional development. Our findings advance existing studies by highlighting how imperceptible geographic-specific disparities can perpetuate unequal human capital endowments from the very beginning of human life. We also show that well-designed and strictly implemented government policy inventions can help to overcome geographical disadvantages.

The rest of this paper proceeds as follows: Section 2 introduces China's IDD prevalence, China's state monopoly of salt starting in 1990, and national implementation of the USI policy in 1994. Section 3 describes our data. Section 4 formulates our identification strategy. Section 5 presents the empirical results. Section 6 concludes.

2. Background

2.1. Iodine deficiency disorders in China

Historically, China was among the countries most seriously affected by IDD. A nationwide census conducted in the 1980s found that IDD was pervasive in most areas in China, threatening a population of 425 million that accounted for roughly 40% of the total population living in IDD-affected areas throughout the world.[8] Fig. 1 maps the spatial distribution of China's county-level goiter prevalence in 1980–1984. Almost every province (except for Shanghai) suffered from the incidence of goiter in the early 1980s to varying extents.

Although a limited number of counties in China gained access to iodized salt in the early 1960s, large-scale salt iodization campaign against IDD did not begin until the late 1970s. In 1979, China's Ministry of Health issued its first official salt iodization policy, which aimed to eradicate IDD in seriously affected areas essentially. Up to the end of 1982, there were 627 counties in China which had ever supplied iodized salt.[9] Although the first wave of salt iodization in the early 1980s had made some progress, IDD continued to be a public health challenge facing the Chinese government. By 1993, there were still six million babies born every year in the iodine-deficient areas. The average IQ of children born in iodine-deficient areas was 10–15 percentage points lower than those in iodine adequate areas.[10] These early efforts failed to eradicate IDD for two reasons. First, the central government only made seriously-affected areas a policy priority and paid little attention to those counties with a goiter prevalence rate under 3%, the official policy criterion for defining whether a county was "affected" by IDD.[11] Second, the salt iodization campaign in the 1980s was loosely enforced due to a lack of coercive action. Non-iodized salt was still available in iodine-deficient counties because the state did not monopolize salt production, distribution, or sales until 1990.

2.2. China's state monopoly on salt after 1990

China's central government enacted *Regulations on the Salt Industry* on March 2, 1990. At the heart of this administrative regulation is the introduction of a state monopoly on salt production, distribution, and sales. The government has strictly prohibited private production, distribution, or sales of salt since 1990. Any offenders are subject to being charged with criminal and civil liabilities. Furthermore, local branches of China's state-owned salt industry corporations (including the China National Salt Industry Corporation owned by the central government and other salt industry corporations owned by subnational governments) could only manage salt sales within their administrative regions.[12] The state also directly regulated prices for edible salt in the market. China's state monopoly of edible salt laid a solid foundation for the subsequent USI policy.

2.3. China's USI policy in 1994

WHO recommends universal salt iodization (USI) as the cheapest and most efficient way to prevent IDD, especially for developing countries with large populations living in iodine-deficient areas. According to WHO (2007)'s definition: "USI involves the iodization

[7] See Banerjee et al. (2017) for a detailed discussion.

[8] Data source: *Plan for eliminating iodine deficiency disorders in China in 2000* (*Zhongguo 2000 nian xiaochu dian quefa bing guihua gangyao*), Ministry of Health, 1993.

[9] Appendix Fig. A1 displays the rollout of salt iodization in China in several specific years. Our subsequent analyses will fully account for the potential confounding effect brought about by those counties which already had access to iodized salt by the end of 1982.

[10] Data Source: *Outlines for eliminating iodine deficiency disorders in China in 2000* (*Zhongguo 2000 nian xiaochu dian quefa bing guihua gangyao*), Ministry of Health, 1993.

[11] *The Interim Rules for Prevention and Treatment of Endemic Goiter by Salt Iodization* (*Shiyan jiadian fangzhi dian quefa bing zanxing banfa*), was enacted by the Ministry of Health on December 21, 1979.

[12] China's state salt monopoly ended on January 1, 2017.

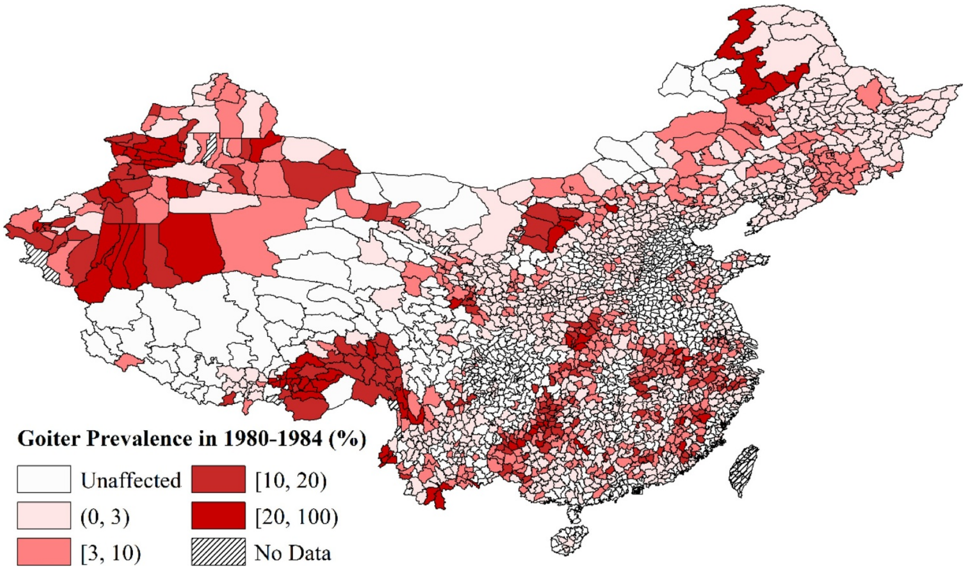

Fig. 1. Goiter prevalence in 1980–1984.
Data Source: The Atlas of Endemic Diseases and their Environments in the People's Republic of China.

of all human and livestock salt, including salt used in the food industry. Adequate iodization of all salt will deliver iodine in the required quantities to the population on a continuous and self-sustaining basis." Thanks to the steady and inelastic demand for salt in daily diets, a small amount of salt fortification can provide adequate iodine to meet the needs of the human body. By 2008, over 120 countries had implemented some degrees of salt iodization, at least 97 of them had issued laws, regulations, or standards about salt iodization, and 34 countries had achieved USI, covering 70% of households throughout the world (UNICEF, 2008).

China's campaign against IDD gained renewed momentum in September 1990, when the World Summit for Children issued the *World Declaration on the Survival, Protection and Development of Children* and drafted the *Plan of Action for Implementing the Declaration*. China's then-Premier Li Peng signed these two documents on behalf of China in March 1991, solemnly declaring to the world that China would generally eradicate IDD by the end of the 20th century. The fact that a top leader of the Chinese government committed to the international community implied that China intended to accomplish this goal by all means. In August 1994, the State Council issued an official mandate that China would launch nationwide USI on October 1, 1994.[13] According to this USI policy, as recommended by WHO, all counties throughout China should supply iodized salt (except for 22 officially approved counties with high water iodine levels and Tibet).[14] As a result of this mandate, the number of uncured goiter patients dropped dramatically from 16.1 million in 1995 to 8.7 million in 2001,[15] and cretinism in newborns was generally eliminated.[16]

Compared to salt iodization policies in other countries, several distinctive features characterized China's USI. First, China instituted a state monopoly on salt production, distribution, and sales. Private production, distribution, or sales of salt have been strictly prohibited since 1990. Local branches of China's salt industry corporation were only authorized to manage salt sales within their administrative regions. This regionally-based state monopoly means that households would have no access to non-iodized salt once their county was covered by USI. Second, China's USI since 1994 was universally imposed throughout the country in a short time, leaving little room for local strategic reactions to the policy and thus contributing a fruitful natural experiment setup. Third, drawing on the lessons of weak enforcement from the first wave of salt iodization in the 1980s, China's central government organized a sophisticated national surveillance program on salt iodization, effective since 1995, to ensure the strict enforcement of USI.

3. Data

3.1. County-level data

This paper's analysis employs a comprehensive dataset of county-level information on the geographic distribution of IDD prevalence, water iodine content, and iodized salt supply drawn from China's Iodine Deficiency Census in the 1980s, which is compiled

[13] The title of the State Council mandate is *Stipulations on the Enforcement of Salt Iodization to Eliminate Iodine Deficiency Disorders (Shiyan jiadian xiaochu dian quefa weihai guanli tiaoli)*, issued on August 23, 1994.

[14] Tibet was excluded in the 1994 wave of USI due to some technical difficulties since Tibet was one of China's most underdeveloped areas.

[15] Data source: *China's Health Statistical Yearbook*, various years.

[16] According to Chen and Hetzel (2010), "Endemic cretinism includes two syndromes: a more common neurological disorder with brain damage, deaf mutism, squint and spastic paresis of the legs and a less common syndrome of severe hypothyroidism, growth retardation and less severe mental defect. Both conditions are due to dietary iodine deficiency and can be prevented by correction of iodine deficiency before pregnancy."

from *The Atlas of Endemic Diseases and their Environments in the People's Republic of China*. This data source, however, has one main drawback: it only reports the ranges of goiter and water iodine content (categorized by several groups) instead of their continuous values for each county.[17] Considering this restriction, we define a dummy variable (labeled *Highgoi*) indicating whether a county's goiter prevalence rate surpasses 3% in 1980–1984 to measure county-level IDD prevalence before the enforcement of USI. As Section 2.1 explained, the Chinese government explicitly introduced this 3% cutoff to define high goiter counties. In our final sample, 481 counties (26% of the full sample) are high goiter counties.[18] A rich epidemiology literature shows that the IDD prevalence rate in China rises sharply in areas where water iodine content is below 5 μg/L (Yu et al., 2004; Wang et al., 2011). Therefore, we define a dummy variable indicating whether a county's average water iodine content is less than 5 μg/L, which we use as an instrumental variable for IDD prevalence in later analyses.

We consider several crucial time-invariant county characters, including whether a county had supplies of iodized salt before 1982, a county's distance to China's nearest coastline to capture its residents' access to seafood (alternative ways of iodine intake), and whether a county is located in a pastoral area to account for the potential influence of dietary habits.[19] County-level geographic information used in this paper comes from China's National Geographic Information System (CNGIS).

Finally, we collect data on the spatial distribution of counties affected by three other endemic diseases, namely Keshan Disease, Kaschin-Beck Disease, and Schistosomiasis, to conduct a placebo test.[20] We compile the list of Keshan Disease and Kaschin-Beck Disease affected counties in 1970–1982 from *The Atlas of Endemic Diseases and their Environments in the People's Republic of China,* and that of Schistosomiasis affected counties in 1981 comes from *The Atlas of Schistosomiasis Infection in the People's Republic of China*.

All of the county-level data are adjusted to administrative boundaries in 2005. We exclude city districts due to their special status in China.[21] All of the counties in Tibet are also excluded because of data availability. Our final sample includes 1883 counties, covering 89% of China's entire population.

3.2. Individual-level data

Our data on individuals' characteristics (such as age, gender, educational attainment, and health status) are drawn from China's population mini-census in 2005 (covering a 0.2% random sample of China's total population in 2005).[22] It is the best data available for us at present. We focus on individuals born in 1987–1997 for two reasons. On the one hand, the National People's Congress of China passed *Compulsory Schooling Law* in April 1986 requiring every Chinese citizen to receive at least nine years of compulsory education, which came into effect on July 1, 1986. Therefore, children born after 1986 are presumed to be immune from the disturbing impacts of the *Compulsory Schooling Law*. On the other hand, rural children were allowed to attend primary school when they were eight years old in some provinces (e.g., Inner Mongolia); thus, we restrict our sample to those born before 1998 to rule out the potential confounding effects of different school entrance ages.[23] The USI was enacted in October 1994, and the birth cohorts affected by USI would be those who were born in 1995–1997 and aged 8–10 on November 1, 2005 (the reference time of the 2005 population mini-census). Given that these individuals had not reached the normal age for entering middle school, the most meaningful outcome of interest will be whether they attended primary school.

Our main dependent variable is a dummy indicating whether a child had ever enrolled in primary school.[24] In the 2005 population mini-census, each household head was asked to self-assess current health status for each of his (or her) family members with four default choices: healthy, capable of having normal work and life, unable to take care of oneself, or hard to tell. While the answer to this question may encompass several dimensions of health status, it mainly reflects physical health. Previous literature demonstrates that self-reported health status is a good predictor of health (Idler and Benyamini, 1997; Hoynes et al., 2016). Therefore, we construct a dummy variable—*Healthy*—indicating whether a child's health status was evaluated as healthy as an outcome to help rule out a competing channel that the USI policy mainly takes effect through improving physical health.

We use an individual's registered address in China's strict household registration system (well-known as the *hukou* system) instead of his (or her) current living address in 2005 when the population mini-census was undertaken.[25] Every Chinese citizen is required to

[17] For instance, the intervals of goiter prevalence rate include 0, (0, 0.03), [0.03, 0.1), [0.1, 0.2), [0.2, 0.3) and [0.3, 1).

[18] Our main empirical findings are robust to employing alternative thresholds to define high goiter counties. The results are available upon requests.

[19] People living in pastoral areas generally eat more meat. Considering the concentration of iodine throughout the food chain, they might have a better situation with regard to IDD.

[20] Keshan disease is a congestive cardiomyopathy caused by a combination of dietary deficiency of selenium and the presence of a mutated strain of Coxsackievirus. Kashin-Beck disease is a chronic, endemic type of osteochondropathy that is mainly distributed from northeastern to southwestern China, involving 15 provinces. Schistosomiasis is caused by digenetic blood trematodes. The spatial distribution of the three major endemic diseases are plotted in Fig. A2.

[21] The results, which we will present in Section 5.3, are highly robust to the inclusion of city districts.

[22] The Chinese government conducts a comprehensive population census every ten years and a 1% randomly sampled mini-census every five years in-between full population censuses. Specifically, the recent population censuses were conducted in 1990, 2000 and 2010, and mini-population censuses were conducted in 1995, 2005 and 2015. However, individual-level data for the 2010 and 2015 population censuses are still unavailable. Our analyses' data set is a 20% random sample of the original 2005 mini-census, which is provided by China's National Bereau of Statistics.

[23] In Section 5.3, we will further discuss the potential confounding effects of delayed schooling age in underdeveloped areas.

[24] Specifically, the value of those school-age children who had dropped out of school was assigned as one.

[25] For more details about China's *hukou* System, please refer to the introduction in Chan(2015).

be registered in the *hukou* system after birth. Under the *hukou* system, moving one's *hukou* across counties was difficult (especially for rural citizens) in the 1990s. Strong disincentives existed: citizens who did not hold the local *hukou* of a particular place could not access public services (such as public schools, medical insurance, and unemployment benefits) reserved for the *hukou*-holders. Moreover, even if parents worked in another county, their children—the so-called “left-behind children” in China—typically remained in the hometown. In this way, we can mitigate concerns about endogenous migration to a great extent. As a final way of confirmation, we construct a dummy variable *Migration* indicating whether an individual's living place was different from his or her registration place in the *hukou* system to address this issue.

Table 1 presents the summary statistics for the main variables used in our subsequent analyses.

4. Empirical strategy

We formulate a difference-in-differences specification to identify the causal effect of USI on primary school enrollment as follows :[26]

$$y_{ict} = \beta Highgoi_c \times Post_t + \mu_c + \gamma_t + \delta_{pt} + \theta \mathbf{X_c} \times \gamma_t + \varepsilon_{ict} \quad (1)$$

where subscripts *i, c, p*, and *t* index individual, county, province, and birth cohort year. y_{ict} denotes the outcome variables. β is the parameter of our interest identified from variation within counties across birth cohorts. $Highgoi_c$ is an iodine deficiency disorder measurement (i.e., whether a county was defined as a high goiter county according to the levels of goiter prevalence rate in 1980–1984) in county *c*. Since the USI policy was enacted in October 1994 and IDD mainly affects nervous system development *in utero*, the first affected cohort was born in 1995. It is noteworthy that even though the central government announced the USI policy would start on October 1, 1994, there might be some delays in the enforcement of the policy given that transporting and distributing iodized salt takes time. Therefore, it is difficult to assign a precise starting time of the USI policy for each county. In practice, we arbitrarily let $Post_t$ equals 1 for every individual born after 1995 and 0 if otherwise. This approach would lead us to underestimate the real policy effect since we regard some children born between October 1994 and December 1994 who might receive partial treatment as non-treated cohorts. μ_c denotes county fixed effects, and γ_t denotes birth cohort fixed effects. We also include province-cohort fixed effects δ_{pt} to absorb province-by-cohort invariant confounders. The standard errors of ε_{ict} are clustered at the county level.

As is standard in difference-in-differences estimations, interpreting our estimated coefficient as a causal effect relies on one necessary condition: a parallel trend before the policy intervention between treatment and control groups. We follow Duflo (2001) to control for the interaction of a variety of county characteristics $\boldsymbol{X_c}$ with birth cohort fixed effects γ_t to allow their impact on primary school enrollment to vary by birth cohorts. These county characteristics include whether a county had already gained access to iodized salt before 1982, whether a county locates in a pastoral area and a county's distance to China's nearest coastline. We also report event study estimates and conduct a full set of other robustness checks to verify the parallel trend assumption.

Another potential threat to our estimation is the confounding effects stemming from endogenous migration. As we have documented above in Section 3.2, the use of an individual's registered address in China's *hukou* system instead of his (or her) current living address in 2005 can mitigate this concern to a great extent. Furthermore, endogenous migration of households in response to variation in IDD prevalence across regions, which would threaten our identification strategy, was unlikely to have occurred because county-level IDD prevalence rate data was not made public. Therefore, people's awareness of IDD endangerment would not drive migration across counties. To further eliminate this worry, we also investigate USI's impact on *Migration* (a dummy variable indicating whether an individual's living place was different from her registration place in the *hukou* system) to provide additional quantitative confirmation.

5. Results

5.1. Event study estimates

Before proceeding to our main empirical results, we first formally test the parallel trend of primary school enrollment between treatment and control groups. Table A1 presents the descriptive statistics of primary school enrollment by birth cohorts. Before the implementation of USI in 1994, there was a marked difference in the average primary school enrollment rate between high goiter and low goiter counties. However, the pattern exhibited a striking break after 1994 and the difference between high goiter and low goiter counties vanished for those birth cohorts of 1995–1997, which provides suggestive evidence on the positive effect of USI.

To formally investigate the dynamic patterns of primary school enrollment rate across different birth cohorts, we conduct an event study by interacting $Highgoi_c$ with a full set of birth cohort dummies as in Eq. (2):

$$y_{ict} = \sum_{k=1987}^{1997} \beta_k Highgoi_c \times \gamma_k + \mu_c + \gamma_t + \delta_{pt} + \theta \mathbf{X_c} \times \gamma_t + \varepsilon_{ict} \quad (2)$$

The cohort 1994 is omitted as the reference group. Other symbols share the same meaning as those in Eq. (1). Fig. 2 displays the estimated coefficients along with 95% confidence intervals for β_k in our event study specification in Eq. (2). The estimates in the pre-

[26] Throughout this paper, we use linear probability models, which allow a straightforward interpretation of the estimated coefficients. More importantly, since our econometric specification controls for a large number of fixed effects and we use population census data with a large sample size, estimating nonlinear discrete choice models would involve daunting computing difficulties.

Table 1
Descriptive statistics.

Variables	Full sample Obs.	Mean	S.D.
Panel A. County-level Variables:			
High goiter	1883	0.255	0.436
Salt iodized, 1982	1883	0.337	0.473
Distance to coastline (measured by radian degree)	1883	6.333	6.429
Pastoral area	1883	0.115	0.319
Low iodine	1883	0.510	0.500
Panel B. Individual-level Variables:			
Enrolling in primary school	346,674	0.990	0.101
Healthy	346,674	0.994	0.0755
Migration	346,674	0.0561	0.230

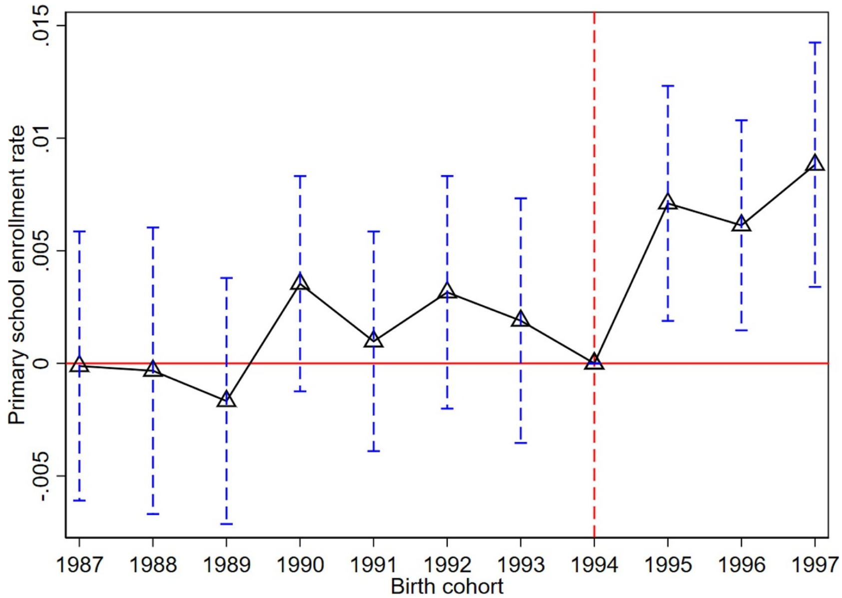

Fig. 2. Event study.
Notes: This figure reports the estimated coefficients along with 95% confidence intervals for a variety of birth cohort dummies in Eq. (2). The cohort 1994 is omitted as a reference group. .

USI period are statistically indistinguishable from zero in stark contrast with a statistically significant and drastic change beginning in 1995. Overall, Fig. 2 visually depicts a time pattern of primary school enrollment for high and low goiter counties generally consistent with the parallel trend assumption of our DID strategy.

5.2. USI's effects on primary school enrollment

Table 2 reports our baseline difference-in-differences results. Column (1) only includes the basic controls of county, birth cohort, and province-by-cohort fixed effects, and column (2) further controls for flexible cohort trends varying by a set of pre-determined county characteristics $\boldsymbol{X_c}$.[27] Both columns report a significantly positive effect of the USI policy on primary school enrollment. Taking column (2) as our preferred specification for interpretation, we find that high goiter counties achieve a 0.6 percentage point increase in primary school enrollment compared to low goiter counties as a result of USI. Admittedly, the magnitude of our estimated USI's policy effects might initially appear to be a little bit small since the primary school education attendance there has already reached a high level (99% on average in our sample) in our sample period. However, a simple back-of-the-envelope calculation implies that 117,120 children in high goiter counties during our sample period were brought back to primary school as a result of USI, accounting for approximately 13% of the uneducated children in China.[28]

[27] Our key results are highly robust to the inclusion of several time-varying controls at the county-cohort level, such as total fiscal expenditures or total educational expenditures. These robustness checks are not reported here but available upon request.

[28] According to the 2005 population mini-census, there were about 19.52 million children aged 7–9 years old in high goiter counties, accounting

Table 2
The effects of USI on primary school enrollment.

Dep. Var.	(1) Enrolling in primary school	(2)
High goiter × Post	0.0063***	0.0060***
	(0.001)	(0.001)
Dep. Mean	0.990	0.990
County FE	YES	YES
Cohort FE	YES	YES
Province × Cohort FE	YES	YES
Controls	NO	YES
Observations	346,674	346,674
Num. of Clusters	1883	1883

Notes: This table reports our baseline difference-in-differences estimations of the USI's effects on primary school enrollment. County-level clustered standard errors are in parentheses. *** denotes significance at 1%, ** at 5% and * at 10%.

Next, we try to situate our estimate in the existing literature by translating it into an effect on average years of schooling, which can be compared with previous studies' estimates (e.g., Field et al., 2009; Politi, 2014; Adhvaryu et al., 2019). According to the aggregate data of China's population mini-census in 2015, people who had a primary school education and were born in 1995–1997 have average years of schooling of 12.69. To be cautious, we assume that the children affected by the USI policy only received an additional six years of schooling. Multiplying our estimated policy effects by six suggests that China's USI leads to an increase in the average years of schooling of the affected group by 0.036 years (equivalent to 13.14 days). This effect on average years of schooling is comparable to previous estimates based on a historical natural experiment of the United States (about two weeks for females and even smaller and statistically insignificant for males) in Adhvaryu et al. (2019) and the most optimistic estimate (0.065 years) by Politi (2014) for Switzerland.[29] A more optimistic analysis provided by Field et al. (2009) finds an average policy effect of 0.35–0.56 additional years of schooling as a result of receiving iodization treatment. We should be cautious about this estimate since the replication work by Bengtsson et al. (2019) only find an effect on average years of schooling ranging from 0.026 to 0.155 and all of these estimates are statistically insignificant. Nevertheless, this calculation indicates that our estimated USI policy effect is at least comparable to the estimates in other contexts in terms of magnitude. Given its huge population scale, China's USI policy should have more profound economic and social implications.

5.3. *Threats to identification and robustness checks*

We will next present additional results to deal with potential threats to our identification strategy and to check whether our baseline results are sensitive to alternative econometric specifications and considering a variety of alternative conjectures.

5.3.1. *Falsification test*

There is a possibility that our results simply capture changes in pre-existing county trends that began before the USI policy. We use all possible years (1988–1994) as a false USI starting year and define $Post_t$ respectively for the seven years. The results, which are reported in Fig. 3, show that none of the false treatments produces significant effects on primary school enrollment and the magnitude of each estimated coefficients is small compared with our baseline estimate (0.006). This falsification test helps us to affirm that our main results in Table 2 are not likely to be driven by any pre-existing county trends that have not been absorbed by our baseline controls.

5.3.2. *Placebo tests using other endemic diseases*

To reinforce our DID results, we use three other major endemic diseases, Keshan disease, Kaschin-Beck disease, and Schistosomiasis, to conduct placebo tests. Just like IDD, these three diseases are also related to specific geographical factors, but they have nothing to do with IDD. If the USI policy only works in a manner associated with the spatial distribution of IDD, we should not see any significant effects using regressors constructed for Keshan Disease, Kaschin-Beck disease, and Schistosomiasis. The results presented in Table 3 accord with this expectation. The estimates in columns (1)–(3) are negative and statistically insignificant, in stark contrast with our baseline results using IDD. This practice helps to alleviate the concern that our results are driven by contemporaneous improvements in health status induced by the eradication of other endemic diseases.

(*footnote continued*)
for 21.6% of the whole sample. 19.52*0.006*1,000,000 = 117,120. 0.216*0.006/(1-0.990)*100% = 12.96%.

[29] Politi (2014) does not offer a direct estimate on average years of schooling but find a 1.05 percentage points increase of secondary education graduation rate and a 0.474 percentage points increase of tertiary education graduation rate resulting from the introduction of iodized salt in Switzerland. For simplicity, we optimistically assume that the additional average years of schooling for secondary school and tertiary school graduates are 3 and 7 years. The upper bound for the policy effects of Switzerland's salt iodization should be 0.0647 (3*0.0105 + 7*0.00474) years.

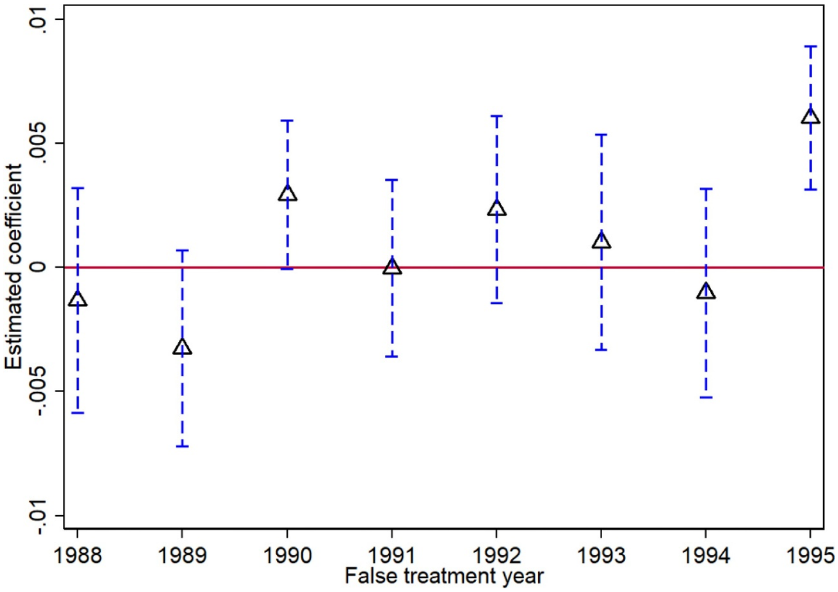

Fig. 3. Falsification test.
Notes: This figure conducts a series of falsification tests by using all possible false treatment times (1988–1994) to construct our main regressor. We focus on the sample born in 1987–1994 to tease out the real treatment effect. We also include our baseline estimate (0.006) using the real treatment time (1995) as a reference. County-level clustered standard errors are in parentheses. .

5.3.3. Robustness to alternative geographic samples and model specifications

First, one may worry that our findings are sensitive to specific geographic sample choices since our baseline regressions drop city districts from the sample. To increase transparency, we bring back all of the sample in city districts and re-run our baseline regression in column (1) of Table 4. The DID estimate still reveals a significant policy effect, although the magnitude decreases to some extent since our main results are exclusively driven by children born in rural areas as we document later in Section 5.5. Second, we exclude from the sample 22 officially approved counties with high water iodine levels where USI was not implemented and repeat our baseline regression in column (2) and the result is broadly similar. Third, we exclude from the sample iodine adequate counties where the average water iodine content is larger than 5 μg/L. The result is reported in column (3), where the point estimate increases from 0.006 in our baseline specification to 0.0086. This robustness check boosts our confidence that our finding derives primarily from USI's blocking effect on IDD. Fourth, one may have concerns that counties with salt iodized before USI would experience a non-parallel trend of primary school enrollment against their counterfactuals, which might drive our findings. Six hundred thirty-five counties (33.7% of our full sample) had already gained access to iodized salt until 1982. To formally address this concern, we exclude these counties. The point estimate in column (4) of Table 4 from this subsample increases slightly from 0.006 to 0.0061 and is still

Table 3
Placebo test using three other major endemic diseases.

Dep. Var.	(1) Enrolling in primary school	(2)	(3)
Keshan × Post	−0.0031 (0.0021)		
Kaschin-Beck × Post		−0.0016 (0.0024)	
Schistosomiasis × Post			−0.0007 (0.0013)
Dep. Mean	0.990	0.990	0.990
County FE	YES	YES	YES
Cohort FE	YES	YES	YES
Province × Cohort FE	YES	YES	YES
Controls	YES	YES	YES
Observations	346,674	346,674	346,674
Num. of Clusters	1883	1883	1883

Notes: This table employs three other major endemic diseases in China to conduct a placebo test. *Highgoi* in our baseline difference-in-differences specification is replaced by three dummy variables indicating whether a county was affected by Keshan disease, Kaschin-Beck disease or Schistosomiasis in each column. County-level clustered standard errors are in parentheses. *** denotes significance at 1%, ** at 5% and * at 10%.

Table 4
Robustness checks.

Dep. Var.	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Enrolling in primary school						
High goiter × Post	0.0052***	0.0062***	0.0086***	0.0061***	0.0045**	0.0040**	0.0046***
	(0.001)	(0.001)	(0.002)	(0.001)	(0.002)	(0.002)	(0.002)
Dep. Mean	0.990	0.990	0.989	0.989	0.990	0.991	0.991
County FE	YES	YES	YES	YES	YES	YES	YES
Cohort FE	YES	YES	YES	YES	YES	YES	YES
Province × Cohort FE	YES	YES	YES	YES	YES		YES
Controls	YES	YES	YES	YES	YES	YES	YES
County-specific Linear Time Trend					YES		
Prefecture × Cohort FE						YES	
Observations	390,506	342,428	156,799	223,519	346,674	346,662	264,168
Num. of Clusters	2066	1861	961	1248	1883	1883	1355

Notes: This table conducts a battery of robustness checks for our baseline difference-in-differences results. In column (1), we include the sample in city districts to address the concern that our results are driven by sample selection. Column (2) excludes sample in high water iodine counties where USI was not implemented. Column (3) excludes sample in iodine adequate counties where the average water iodine content is larger than 5 µg/L. Column (4) excludes sample from counties with iodized salt before 1982. Column (5) further controls for county-specific linear time trend. Column (6) controls for prefecture-by-cohort fixed effects instead of province-by-cohort fixed effects. Column (7) excludes sample in the provinces where children were allowed to attend primary school after seven years old. County-level clustered standard errors are in parentheses. *** denotes significance at 1%, ** at 5% and * at 10%.

highly significant. Fifth, we allow each county to have its linear time trend in column (5) and our result still holds. Sixth, we apply the most demanding specification in column (6) by controlling for prefecture-by-cohort fixed effects. In so doing, we are comparing counties within the same prefecture, which are geographically close to each other. The magnitude of our estimated coefficient drops slightly but remains highly significant, implying that the spatial clustering of the IDD prevalence might not contaminate our findings.

5.3.4. Ruling out the confounding effects of delayed primary school enrollment

There exists a possibility that children in poor regions may postpone primary school enrollment but will still attend primary school at a later age. If this is the case, our main finding might only reflect the effects of delayed primary school entry instead of the permanent lifetime gains (i.e., from never enrolling to ever enrolling in primary school), which might put us at risk of exaggerating our estimated USI policy effects. To formally address this concern, we collect detailed historical administrative laws and regulations on legal schooling age promulgated by each province government.[30] Nine provinces in our sample, Inner Mongolia, Jilin, Jiangxi, Guangxi, Guizhou, Yunnan, Qinghai, Ningxia, and Xinjiang, allowed children to enroll in primary school after seven years old in certain circumstances. To isolate the potential confounding effect of the differences in legal schooling age which might correlate with the spatial distribution of high goiter counties, column (7) of Table 4 trims counties in those provinces allowing for older enrollment age and the result is highly similar.

5.3.5. Ruling out alternative conjectures

As mentioned in the introduction, IDD is an endemic disease which inflicts permanent damage to children's cognitive abilities and thus affects their schooling enrollment. A large literature has documented abundant evidence on the role that IDD plays in destroying cognitive ability (Bleichrodt and Born, 1994; Zimmermann et al., 2008; Feyrer et al., 2017). Our population census dataset does not have information on children's cognitive abilities, so we cannot directly test the linkage between the USI policy and improvement in cognitive ability. As a related attempt, we want to examine whether the USI policy affects the physical health of birth cohorts since 1995. In principle, the USI policy should not work directly on the physical health of the affected children, so if the USI policy works, we should not find any evidence of its effect on physical health. We construct a dummy variable from the 2005 population mini-census, namely *Healthy*, according to interviewees' assessment as proxies to children's physical health. We re-run our baseline DID estimation using this measure as the dependent variable and present the result in column (1) of Table 5. The estimate is small in magnitude and statistically insignificant, revealing no evidence that the USI policy improves the self-reported health status. This finding lends support to our claim that USI does not affect primary school enrollment through the physical health channel. In column (2), we investigate USI's effects on *Migration* (a dummy variable indicating whether an individual's living place was different from his or her registration place in the *hukou* system). The point estimate is not only statistically insignificant but also very small in magnitude, which helps rule out the possibility that migration drives our findings. Finally, we add both *Healthy* and *Migration* as covariates in column (3). It is not surprising to see a strong positive correlation between health status and primary school enrollment. Moreover, most migrants in China moved from the countryside to urban areas, where their children would have comparatively better if still less than full access to educational opportunities. The point estimate of our DID regressor of interest remains stable, thus indicating little evidence that other competing hypotheses—such as physical health and endogenous migration patterns associated with USI—account for our findings.

[30] The original documents of these laws and regulations are available upon request.

Table 5
Ruling out alternative hypotheses.

Dep. Var.	(1) Healthy	(2) Migration	(3) Enrolling in primary school
High goiter × Post	0.0009	−0.0012	0.00571***
	(0.001)	(0.003)	(0.00145)
Healthy			0.349***
			(0.0119)
Migration			0.00160**
			(0.00069)
Dep. Mean	0.994	0.0561	0.990
County FE	YES	YES	YES
Cohort FE	YES	YES	YES
Province × Cohort FE	YES	YES	YES
Controls	YES	YES	YES
Observations	346,674	346,674	346,674
Num. of Clusters	1883	1883	1883

Notes: This table reports additional results to rule out alternative hypotheses. *Healthy* is a dummy denotes whether the self-assessed health status for a child by the household head was "healthy". *Migration* is a dummy indicating whether an individual's living place was different from her registration place in the *hukou* system. County-level clustered standard errors are in parentheses. *** denotes significance at 1%, ** at 5% and * at 10%.

5.4. Instrumental variable results

The basic DID strategy underpinning Eq. (1) might be threatened by endogeneity arising from nonrandomness of IDD for two reasons. First, our IDD proxy suffers from measurement error since we do not have IDD prevalence rate data right before 1995 and so use pre-determined values in 1980–1984 as a substitute proxy. Second, potential pitfalls arise when some unobservables correlated with IDD exert heterogeneous effects on school enrollment before and after 1994. On the one hand, county governments with better economic conditions may be more likely to employ propaganda to strengthen people's awareness of IDD's potential dangers. Or those residents with higher social-economic status may be more likely to change their consumption behavior in response to the government's propaganda. On the other hand, counties with better economic conditions were closer to universal primary school enrollment before USI and thus may have little room for further improvement. In these cases, certain omitted variables (e.g., economic development level) are correlated with IDD prevalence rates and have heterogeneous effects on school enrollment in the pre- and post-treatment era, leading our DID estimate to be biased. Therefore, we need to apply an instrumental variable strategy to address the endogeneity issue caused by measurement error and potential omitted variables.

Water iodine content is the first-order determinant of a county's IDD prevalence. The epidemiology literature shows that there is a strong correlation between water iodine content and goiter, and the IDD prevalence rate in China rises sharply in areas where water iodine content is below 5 μg/L (Yu et al., 2004; Wang et al., 2011). These well-documented scientific findings provide us with a natural instrumental variable for IDD prevalence, which is a dummy variable indicating whether a county's water iodine content is less than 5 μg/L (labeled *Low_Iodine*). We map the spatial distribution of China's iodine deficient counties in Fig. 4. It works as a valid IV for two reasons. First, a county's water iodine content directly and significantly affects its level of IDD. Second, since iodine and iodine compounds are not important raw industrial materials, water iodine content is exclusively determined by exogenous local natural conditions shaped in the geological age and therefore should be orthogonal to any unobservables we are aware of that affect IDD prevalence rates. Admittedly, water iodine content still suffers from measurement error to some extent. However, as long as the measurement error of water iodine content is generally orthogonal to the measurement error of IDD prevalence, this instrumental variable is still valid. The first-stage and second-stage regressions are specified in Eqs. (3) and (4) as follows:

$$Highgoi_c \times Post_t = \alpha Low\_Iodine_c \times Post_t + \mu_c + \gamma_t + \delta_{pt} + \theta \mathbf{X_c} \times \gamma_t + \nu_{ct} \quad (3)$$

$$y_{ict} = \beta \widehat{Highgoi_c} \times Post_t + \mu_c + \gamma_t + \delta_{pt} + \delta \mathbf{X_c} \times \gamma_t + \varepsilon_{ict} \quad (4)$$

where Low_Iodine_c is a dummy variable as defined above. $\widehat{Highgoi_c} \times Post_t$ indicates the predicted value of $IDD_c \times Post_t$ in the first-stage regression. Other symbols are defined similarly to Eq. (1).

Columns (1)–(3) of Table 6 present the first-stage, reduced-form, and second-stage results, respectively. The Kleibergen-Paap *F*-statistic is about 84, implying a quite strong first-stage result. The first-stage estimate in column (1) indicates that iodine-deficient counties are more likely to become high goiter counties, echoing well-established scientific evidence that iodine content in the ground layers of the earth is the first-order determinant of IDD. Given the exogeneity of our IV, we can safely argue the intent-to-treat (ITT) estimate in column (2) as a causal effect where the exclusion restriction is not needed. Our reduced-form estimate directly links iodine deficiency to the lower primary school enrollment. This finding makes a solid step forward in highlighting how imperceptible geographic-specific disparities perpetuate the inequality of human capital endowments from the very beginning of human life. We also show that the well-designed and strictly-implemented USI policy contributes to overpower geographical disadvantages (in our context, iodine deficiency in the soil and water). The IV estimate in column (3) shows that the USI policy brings about a 0.93

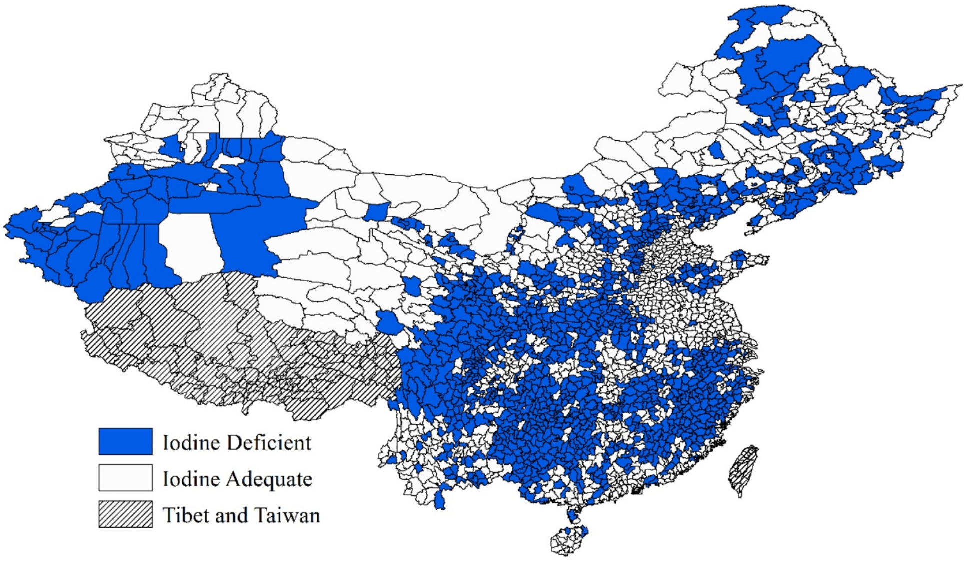

Fig. 4. Spatial distribution of iodine deficient counties in China.
Notes: Counties where the average water iodine content is lower than 5 μg/L are defined as iodine deficient counties, and iodine adequate counties if otherwise. Water iodine content data for counties in Tibet and Taiwan are unavailable.
Sources: The Atlas of Endemic Diseases and their Environments in the People's Republic of China.

Table 6
IV results.

	(1) First-stage	(2) Reduced-form	(3) Second-stage
Dep. Var.	High goiter × Post	Enrolling in primary school	Enrolling in primary school
High goiter × Post			0.0093**
			(0.005)
Low Iodine × Post	0.2087***	0.0019**	
	(0.023)	(0.001)	
Dep. Mean	0.0504	0.990	0.990
Kleibergen-Paap *F* statistics	83.99		
County FE	YES	YES	YES
Cohort FE	YES	YES	YES
Province × Cohort FE	YES	YES	YES
Controls	YES	YES	YES
Observations	346,674	346,674	346,674
Num. of Clusters	1883	1883	1883

Notes: Columns (1)–(3) report first-stage, reduced-form, and second-stage results for the instrumental variable estimation, respectively. County-level clustered standard errors are in parentheses. *** denotes significance at 1%, ** at 5% and * at 10%.

Table 7
Heterogeneous effects.

	(1)	(2)	(3)	(4)
Dep. Var.	Enrolling in primary school			
Sample	Urban citizens	Rural citizens	Male	Female
High goiter × Post	0.0011	0.0064***	0.0039**	0.0078***
	(0.002)	(0.002)	(0.002)	(0.002)
Dep. Mean	0.996	0.989	0.991	0.988
County FE	YES	YES	YES	YES
Cohort FE	YES	YES	YES	YES
Province × Cohort FE	YES	YES	YES	YES
Controls	YES	YES	YES	YES
Observations	39,054	306,559	177,008	169,666
Num. of Clusters	1663	1876	1883	1883

Notes: County-level clustered standard errors are in parentheses. *** denotes significance at 1%, ** at 5% and * at 10%.

percentage point increase in primary school enrollment for high goiter counties compared with low goiter counties, which is approximately 1.55 times the corresponding DID estimate in column (2) of Table 2. The difference suggests that the DID estimate understates the real USI policy effect due to some combination of omitted variables bias and measurement error.

To sum up, applying an instrumental variable approach further confirms our findings in the baseline DID specification.

5.5. A simple cost-benefit analysis

In this subsection, we conduct a rough cost-benefit analysis to better appreciate the economic magnitude of our estimated USI's policy effect.

According to the official data provided by the Chinese government, salt iodization cost approximately 25 RMB per ton of salt in 1995 constant prices. The Chinese central government imposed a new in-price excise tax called the “Salt Iodization Fund” to cover this expenditure; we suppose that this cost was to be paid by the whole population. According to data from the *Chinese Population Nutrition Survey* (CPNS) in 1992, a typical individual in China consumed 13.9 g of salt per day on average. In other words, each consumer paid only 0.127 RMB every year for salt iodization, which took up only 0.003% of the per capita disposable income of urban citizens (4283 RMB) or 0.008% of rural citizens’ income per capita (1577.7 RMB) in 1995.[31] In other words, the per capita economic cost of USI was negligible and should not impair household welfare. We can try another way to make a simple cost-benefit calculation of the USI policy. The aggregate cost of USI was about 153.8 million RMB in 1995. Recall that there were about 19.52 million children aged 7–9 years old in high goiter counties according to the 2005 population mini-census. Applying the DID estimate (0.006) as a lower-bound and the IV estimate (0.0093) as an upper-bound, implementing USI was associated with additional 39,040 to 58,560 children attending primary school every year.[32] This means that the average cost of saving an out-of-primary-school child is about 2626–3940 RMB, which equals 1.66–2.50 times of rural citizens’ per capita annual income in 1995. This cost is presumably small relative to the significant and life-long economic and social benefits of additional schooling. According to the 2005 population mini-census, the average annual wage for illiterate workers in our sample is 1947 RMB compared with an average of 3529 RMB for workers having a primary school education or higher literacy. Suppose an average working time of 35 years per person and the wage gap will translate into a lifetime wage gain of 55,370 RMB. This rough calculation does not account for the rapid growth of China's household income and externalities of human capital and therefore is fairly conservative. Since the cost of USI almost evenly fell on the iodine salt consumers of the entire nation via the “Salt Iodization Fund” levied by China's central government, our estimate yields clear implications for redistribution in favor of the poor people.

5.6. Heterogeneous effects of USI

This subsection explores heterogeneity regarding USI's effects on primary school enrollment, based on two important socio-economic dimensions, including rural-urban difference and gender.

We first look at the rural-urban difference in the USI policy effect by applying DID to urban and rural subsamples separately. Urban citizens generally had easier access to seafood and relevant knowledge about how to prevent IDD, and so we expect that rural people were more sensitive to the effects of the mandatory USI policy. As shown in columns (1)–(2), Table 7, we find that the effects observed in our baseline results are predominantly driven by the policy effect on rural citizens, who are most vulnerable to IDD.

Next, we examine how the USI policy works differently by gender in columns (3)–(4) of Table 7. We can see a larger effect on females, which echoes the findings in existing studies using data from Tanzania and the United States that females are more prone to be affected by IDD (Field et al., 2009; Adhvaryu et al., 2019). Our finding also helps to explain the relatively large initial gender education gap (2.1 percentage points in primary school attendance for people born in 1987–1994 according to the aggregate data provided by *China's Educational Statistical Yearbook, 2002*) and its rapid disappearance after USI in China.

To sum up, children born in rural families and girls benefit more from the USI policy. When generalized to a broader context, these findings speak to a dearth of studies focusing on how public policies help to enhance social justice and mobility (Almond and Currie, 2011; Aizer and Currie, 2014; Chetty et al., 2014). IDD-affected areas are not the lands of opportunity, and children born in these areas are more likely to have limited cognitive ability and lose chances to go to school. Our findings provide strong evidence in support of mandatory universal public health interventions like USI as an effective way to correct inequality at birth and promote social mobility at a low cost.

6. Conclusion

Iodine deficiency disorder (IDD) is the leading cause of preventable mental retardation while universal salt iodization (USI) has been one of the most widely used weapons to fight back against IDD-related health problems. This paper studies the effects of China's USI policy in 1994 on children's later-life educational outcomes. Using population census data, our difference-in-differences strategy compares the school enrollment of cohorts born before and after USI across counties with varying IDD prevalence. Empirical findings suggest that the USI policy increased primary school enrollment by 0.6 percentage points for the policy-affected cohorts. Further investigation suggests that rural children and girls benefit more from USI. Since the costs of USI almost evenly fell on the iodized salt

[31] Data comes from *China's Statistic Yearbook* and *China's Education Statistic Yearbook*.

[32] This calculation is conservative since China's school year age children were still fast-growing in the first decade after the implementation of USI.

consumers through an in-price tax levied by China's central government, our findings yield clear redistribution implications.

We show that a well-designed and strictly-implemented government policy contributes to overpowering initial geographical disadvantages. Our finding also serves as a counterweight to recent clamor and advocacy in China for abolishing USI. Considering that most people might be unconscious of or underrate potential gains from micronutrient supplementation, policymakers should be cautious in handling this issue of tremendous policy relevance.

One main limitation of this paper is that our data only cover a relatively short time window and provides limited outcomes for us to look at the comprehensive effects of the USI policy. The quantification of USI's long-term effects on labor market performance and productivity still awaits future work. Since there has been an increasing interest in detecting human intelligence's impacts on a full battery of socioeconomic outcomes, our research design enabled by China's unique institutional context can easily be extended to future studies on these important issues.[33]

Appendix

Fig. A1,Fig. A2.

Table A1
Descriptive statistics of primary school enrollment by birth cohort.

Birth Cohort	(1) Low Goiter	(2) High Goiter	(3) Diff.
1987	0.989	0.981	−0.008***
	[0.1031]	[0.1350]	(0.0016)
1988	0.991	0.982	−0.008***
	[0.0968]	[0.1311]	(0.0015)
1989	0.991	0.983	−0.009***
	[0.0925]	[0.1301]	(0.0013)
1990	0.991	0.988	−0.003**
	[0.0944]	[0.1077]	(0.0012)
1991	0.991	0.987	−0.004***
	[0.0929]	[0.1139]	(0.0013)
1992	0.991	0.988	−0.003**
	[0.0940]	[0.1096]	(0.0013)
1993	0.991	0.988	−0.003**
	[0.0937]	[0.1068]	(0.0013)
1994	0.992	0.987	−0.005***
	[0.0869]	[0.1116]	(0.0013)
1995	0.991	0.990	−0.001
	[0.0954]	[0.1008]	(0.0014)
1996	0.990	0.990	0.001
	[0.1009]	[0.0977]	(0.0015)
1997	0.988	0.989	0.001
	[0.1103]	[0.1059]	(0.0017)

Notes: This table reports the summary statistics of primary school enrollments by birth cohort in our control group (low goiter counties) and treatment group (high goiter counties). Columns (1) and (2) show means as well as standard deviations in square brackets. Column (3) shows the differences between the high goiter counties and low goiter counties. The standard errors of the differences are reported in parentheses. *** denotes the differences between the two groups is significant at 1%, ** at 5% and * at 10%.

[33] For example, recent experimental research shows that higher intelligence groups cooperated far more than the lower IQ group in a repeated prisoner's dilemma game (Proto et al., 2019).

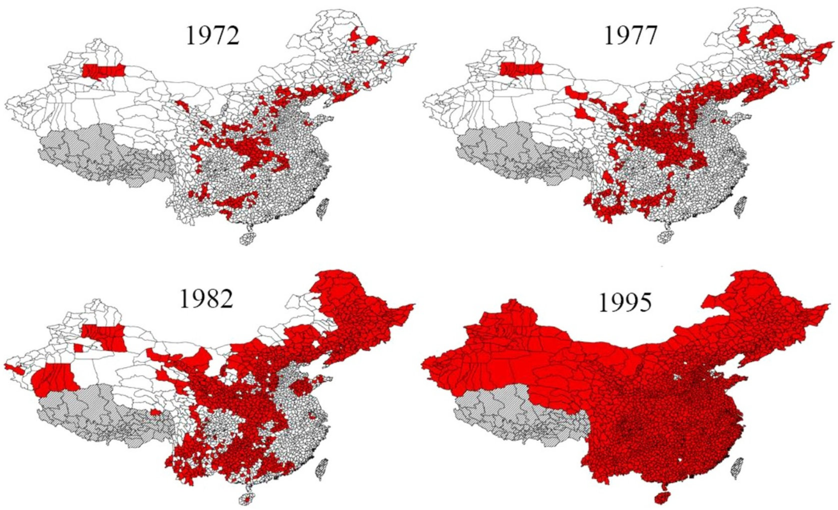

Fig. A1. Salt iodized counties in several years.
Notes: Salt-iodized counties are shaded in red for several specific years which we have information. Counties in Tibet and Taiwan are painted in shadow because they are excluded from our analyses. In 1995, high iodine counties not supplying iodized salt are left blank.
Data Source: The Atlas of Endemic Diseases and their Environments in the People's Republic of China.

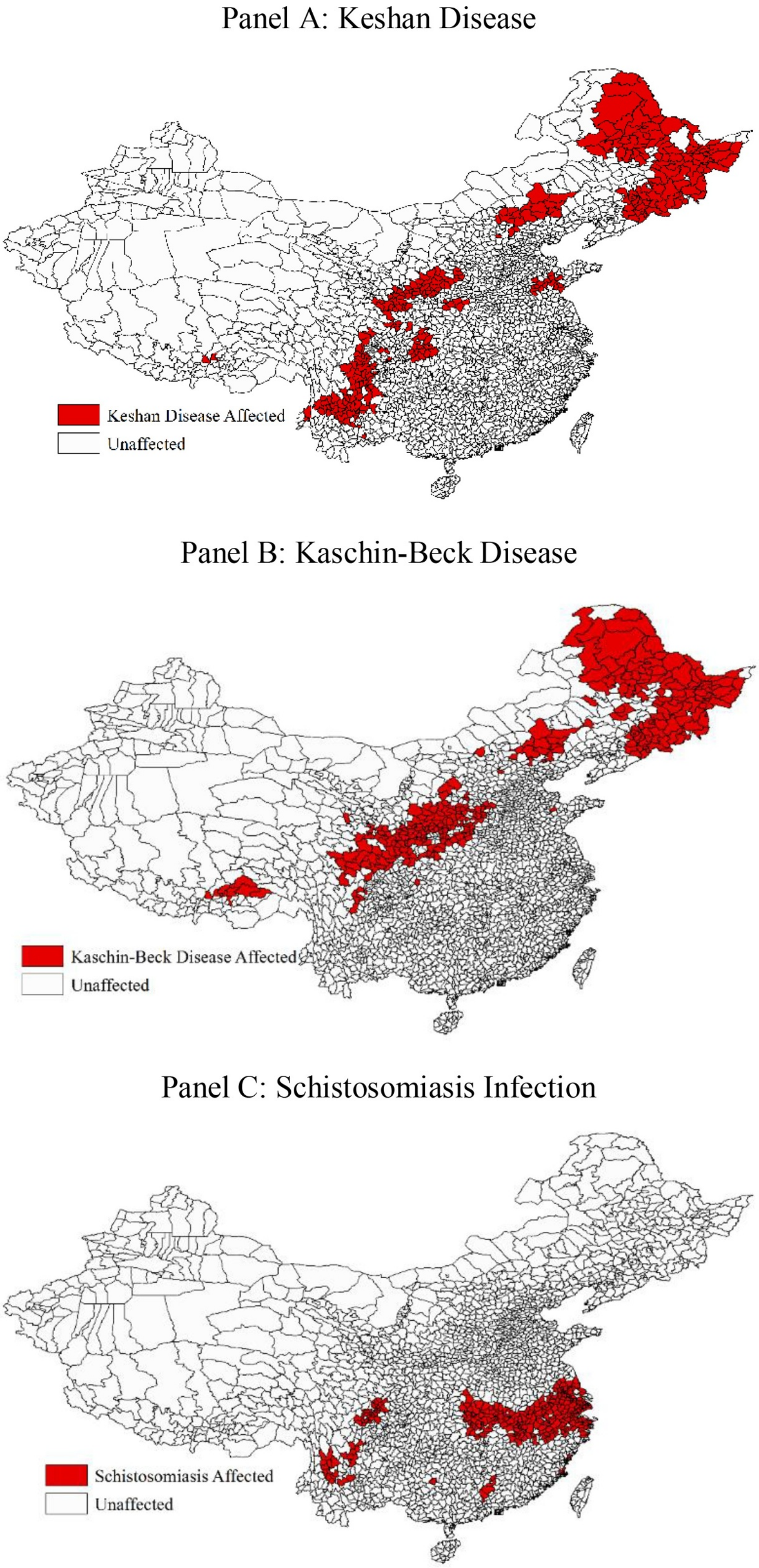

Fig. A2. Falsification tests from three major endemic diseases

Notes: Panels A-B show the spatial distribution of Keshan disease and Kaschin-Beck disease affected counties in 1970–1982 and Panel C shows that of Schistosomiasis Affected counties in 1985.

Date Source: The Atlas of Endemic Diseases and their Environments in the People's Republic of China and *The Atlas of China's Schistosomiasis Infection.*

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