When It Rains It Pours: The Long-run Economic Impacts of Salt Iodization in the United States*

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Abstract

In 1924, The Morton Salt Company began nationwide distribution of iodine-fortified salt. Access to iodine, a key determinant of cognitive ability, rose sharply. We compare outcomes for cohorts exposed *in utero* with those of slightly older, unexposed cohorts, across states with high versus low baseline iodine deficiency. Income increased by 11%, labor force participation rose 0.68 percentage points; and full-time work went up 0.9 percentage points. These impacts were driven entirely by females. We find large impacts early in women's adult lives and muted later-life effects. Women married at later ages and experienced a small increase in educational attainment.

Keywords: fetal origins, iodine, cognitive ability, female labor force participation
JEL Codes: I15, I18, J24, N32

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1 Introduction

Inadequate access to essential micronutrients such as iron, vitamin A, iodine, and zinc has staggering costs in terms of mortality, poor health, and lost productivity in low-income countries (Black et al., 2013). The benefits of improving micronutrient availability in the short term, especially for young children, are clear (Bhutta et al., 2013). But less is known about long-run impacts, particularly of large-scale supplementation policies. How long do the effects of improved access to vital micronutrients last? Do health effects spill over onto socioeconomic outcomes? Which individuals are most affected by blanket campaigns? With notable recent exceptions (Clay et al., 2015; Feyrer et al., 2017; Niemesh, 2015; Politi, 2010, 2014), these questions have received scarce attention, and are the focus of the present study.

We draw lessons from the historical experience of the United States, where until the mid-1920's, natural access to iodine was limited in some areas of the country compared to others. An essential micronutrient, iodine regulates thyroid hormone availability, which determines the density of fetal neural networks (Lamberg, 1991). Physiological studies suggest that iodine deficiency negatively affects cognitive function at all ages, but is particularly detrimental during gestation, when even mild deficiency can greatly hamper cognitive development (Cao et al., 1994). Moreover, the effects of fetal iodine deficiency disorder (IDD) are irreversible: an inadequate supply of iodine in the first trimester of gestation permanently reduces intelligence quotient (IQ), regardless of subsequent supplementation (Hetzel & Mano, 1989; Pharoah & Connolly, 1987; Zimmermann, 2009).[1]

We study the economic impacts of rapid, large-scale salt iodization in the twentieth century US. The Morton Salt Company, the largest salt producer in the US, initiated nationwide iodized salt distribution shortly after the invention of iodine-fortified salt in the mid-1920s. In less than half a decade, the US went from zero to nearly universal availability of iodized salt (Markel, 1987). Iodine deficiency rates plummeted in the following decade, most markedly in areas that were highly iodine deficient prior to the introduction of iodized salt (Brush & Atland, 1952; Hamwi et al., 1952; Schiel & Wepfer, 1976). Feyrer et al. (2017) show that IQ rose substantially – by around 15 points – as a result. Building on this important work, we ask: what happened to the economic outcomes of those whose *in utero* access to iodine improved? Did increased IQ affect incomes, as was true in Switzerland (Politi, 2014) and labor

[1] It bears mention that studies from the medical literature are either correlational or based on animal studies: causal evidence on the effects of iodine exposure in humans is limited. The study by Feyrer et al. (2017) is important in this sense, because it provides the most rigorous evidence to date of the impact of fetal iodine access on adult cognitive performance.

supply? Did men and women benefit differentially? How did these impacts evolve over the life cycle? Did related outcomes like educational attainment and marriage respond differentially?

To identify these effects, we compare outcomes for cohorts born just before iodization (1920-1923) to those born during (1924-1927) and after (1928-1931), across areas with varying pre-iodization deficiency rates. For the latter source of variation, we use pre-iodization rates of goiter, the main physical manifestation of IDD (Love & Davenport, 1920; Olesen, 1929). We follow these cohorts through their productive lives, using data from the 1950-1980 censuses, during which these individuals were 19 to 60 years old. We present estimates of early career outcomes, pooling the 1950 and 1960 censuses, and later career outcomes, using the 1970 and 1980 censuses.

Individuals affected by salt iodization saw improved economic outcomes. Income increased by 11% on average and labor force participation rose by about 0.68 percentage points in the pooled sample of individuals aged 19-60 in the 1950-1980 censuses. Women experienced the largest changes in employment (greater than 1 percentage point) and income (15 percent); indeed, nearly *all* of the pooled effect on these outcomes comes from women. This is consistent with medical evidence that female fetuses are more sensitive to maternal thyroid deficiency than male fetuses (Field et al., 2009; Friedhoff et al., 2000) and also likely reflects the larger scope for improvement among females who exhibit lower employment rates and incomes at baseline.

These estimates mask much larger employment and income effects on females early in their careers (before age 40). We do not see strong evidence that employment effects persist in later census years: individuals affected by salt iodization are not significantly more likely to be in the labor force in the 1970 and 1980 censuses. Impacts on female incomes do persist at later ages, but are smaller and less precisely estimated. This pattern is consistent with impacted women transitioning out of the labor force at later ages to raise families, as has been documented previously, in particular the "career then family" cohorts discussed in Goldin et al. (1997); Goldin & Katz (2002). Supporting this idea, we find that impacted women married at later ages (nearly a quarter of a year) and stay in school for slightly longer.

Like Politi (2010), which focuses on Switzerland's historical experience with salt iodization, we find a small but precisely estimated positive effect on educational attainment. Theoretical effects of increased cognition on schooling are ambiguous, as the direct wage returns to ability in entry-level labor opportunities may counteract any impacts of ability on schooling returns at early ages. Because the magnitude of our estimated effect is very small (equivalent to about two weeks of school), we interpret this result as evidence that both of these opposing effects are in play.[2]

Our study aims to contribute to three literatures. First, we add to the literature on the long-term effects of early life conditions.[3] Much of this "fetal origins" work has focused on demonstrating the impacts of traumatic experiences (disease, natural disasters, environmental factors, etc.) in early life. Fewer studies have estimated the gains to exposure to the purposeful large-scale distribution of resources. The distinction between the two types of studies is important because the latter "shock" can yield actionable information: policies with demonstrated positive impacts can be advocated for and reproduced. A growing set of studies–including **?**, Bleakley (2007), Bleakley (2010), Field et al. (2009), Almond et al. (2010), Politi (2010), Bhalotra & Venkataramani (2015), and Feyrer et al. (2017)–have recently made strides in this direction. We build on this evidence base: the results of these studies and ours offer lessons from historical policy experiments from which present-day policymakers, particularly in developing countries, might profitably draw.

Second, we contribute to the understanding of women's decisions regarding the labor force in the historical United States. We find that labor market effects of iodine are particularly pronounced for women, consistent with evidence from recent studies on the effects of other early life interventions (Bleakley, 2007; Field et al., 2009; Hoynes et al., 2016; Maccini & Yang, 2009). Moreover, this pattern relates to important previous work on the drivers of the marked rise in labor force participation of women over the 20th century. Goldin (1991) and Goldin & Olivetti (2013) estimate that WWII led to a roughly 20 percent rise in female participation for higher-educated women in cohorts born between 1915 and 1924. Bailey (2006) and Goldin & Katz (2002) show that increased access to oral contraceptives led to later marriage, higher likelihood of professional and graduate training in high skill occupations, and increased rate and duration of labor force participation among cohorts born after 1940. We present complementary evidence documenting that salt iodization also contributed to the rise in female labor force participation, generating a 3 percent increase among females born in between the two sets of cohorts studied in these papers.

Finally, we add evidence on the long-run effects of micronutrient fortification campaigns and in particular mass salt iodization as a means of eradicating iodine deficiency. Nearly 2 billion people worldwide–a third of the world's population–do not have adequate access to iodine (De Benoist et al., 2004). Recent estimates from the economics literature suggest that the incidence of iodine deficiency,

[2]This is consistent with Bleakley (2010), who finds mixed results on the effect of malaria eradication on schooling in four different countries.

[3]See Heckman (2006), Almond & Currie (2011), and Currie & Vogl (2013) for useful syntheses.

and thus the returns to reducing IDD, may be very large (Feyrer et al., 2017; Field et al., 2009; Politi, 2010). Policymakers in IDD-endemic countries, as well as the WHO, UNICEF, and other international organizations, have made increasing access to iodine a high priority. Mass salt iodization to prevent IDD is, far and away, the preferred policy: iodizing salt is much cheaper than continuous supplementation in populations with iodine-deficient diets, and, taken with other micronutrients such as iron, is highly cost-effective in terms of fetal and infant deaths averted (Horton et al., 2008).

The rest of the paper is organized as follows. Section 2 discusses iodine deficiency and its prevalence in the early twentieth century, as well as the history of salt iodization in the US. Section 3 discusses our data sources, section 4 our empirical strategy, and section 5 the results. Section 6 concludes with a discussion of the size of the economic benefits of iodization.

2 Background

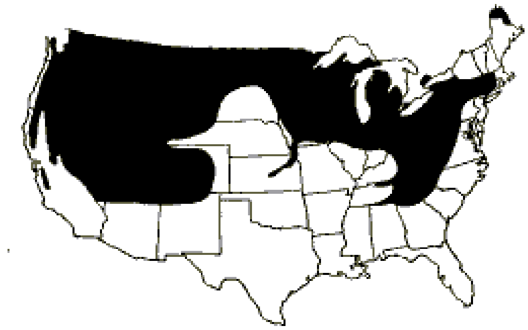
2.1 Iodine Deficiency and its Consequences

Iodine is crucial to the functioning of every body cell. The thyroid gland in the lower part of the neck uses iodine from foods to produce thyroid hormones, which are released into the blood stream to control metabolism (the conversion of oxygen and calories to energy). Optimal iodine intake as recommended by the WHO is very small: a daily dose of 90 μg for children of 0-59 months, 120 μg for ages 6 to 12, 150 μg for older ages (which is the amount found in half a teaspoon of iodized salt), and 200 μg for pregnant and lactating women (Clar et al., 2002). Foods with high iodine content include some milks, leafy vegetables, and seafood, but individuals in areas without natural access to iodine – far from the ocean or in mountain regions susceptible to erosion (Hetzel, 1989) – are at risk of not meeting these recommended levels of iodine intake.

At any point from the fetal stage to adulthood, insufficient iodine intake can cause a number of functional and developmental abnormalities, often referred to as iodine deficiency disorders (IDD). The main physical manifestation of IDD is goiter (the enlargement of the thyroid gland),[4] but other IDDs include hypothyroidism (which results in fatigue, lethargy, slow speech, and thought), impaired mental function, retarded physical development, and increased susceptibility of the thyroid gland to nuclear radiation (De Benoist et al., 2004). This paper focuses on the availability of iodine *in utero*

[4]Goiter may not be visible if iodine deficiency is minimal. On the other hand, iodine deficiency is the primary, but not exclusive, cause of goiter. Goiter, when sufficiently large, may cause complications such as respiratory difficulty.

Figure 1: Simple Goiter Incidence Among US Drafted Men in World War I and Iodine Content of Drinking Water in the US



Simple goiter among drafted men in the US in WW I

Black areas: High goiter incidence, i.e. 6 and more goiter cases per 1,000 drafted men
White areas: Low goiter incidence, i.e. 5 and less goiter cases per 1,000 drafted men

Source: McClendon (1939)

Iodine content in drinking water in the US

Black areas: Iodine-poor, i.e. 22 and less parts of iodine per hundred billion parts of water
White areas: Iodine-rich, i.e. 23 and more parts of iodine per hundred billions parts of water

Source: McClendon and Hathaway (1924)

because fetal iodine levels are particularly crucial for brain development: insufficient iodine intake during gestation can cause irreversible cognitive damage (De Escobar et al., 2004; Zimmermann, 2009).

2.2 The Geography of Iodine Deficiency in the US

The map on the left in Figure 1 illustrates the geographic distribution of goiter incidence across the US based on data from the 1917 WWI draft examinations, which is, to our knowledge, the first nationwide goiter survey in the US. The second map in Figure 1, which highlights areas with low iodine content in drinking water, as reported by then prominent scientist Jesse Francis McClendon, shows a similar "goiter belt" in the northern states.[5] Starting in 1924, Robert Olesen, a surgeon at the U.S. Public Health Service, began collecting data on goiter rates across the country by consulting independent thyroid surveys and directly communicating with state, county, and city health officers. Olesen (1929) concluded that his data from elementary school to college aged samples were consistent with the geographic variation in goiter incidence among WWI recruits in areas where he was able to collect data.

Evidence from these other sources suggests that the draft statistics offer a good representation of

[5]In our estimations, we do not use the water iodine content data, as the author presents numerical information for only 27 states, many of which use data from only one location.

the geographic pattern of iodine availability for the general population. Summarized in Table A1, these draft statistics show considerable variation in goiter prevalence across states even within regions defined by the nine Census divisions. This variation is crucial as it allows us to control for division-level time effects to remove any systematic coincidence between the goiter distribution and geographic differences in economic development over time, such as the North-South divide.

2.3 Introduction of Iodized Salt in the US in 1924

The hypothesis 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). After this, experiments were conducted to study the impact of changes in iodine content on the incidence of goiter in different kinds of animals (Marine & Feiss, 1915; Marine & Lenhart, 1909; Smith, 1917). In the United States, Hall (1914) and Olesen (1915) were the first to record goiter rates in humans in an organized manner. An experiment started in 1917 by scientist David Marine and colleagues, which involved providing iodated syrup to school girls in Ohio, offered the first direct evidence that iodine supplementation could control and prevent goiter in humans (Marine & Kimball, 1917, 1920). This evidence inspired Switzerland to set up prophylactic programs, one of which used salt as an iodization vehicle.

Around the same time as the Ohio experiment, a few other factors placed focus on goiter in humans as a health problem in America (Annegers & Mickelsen, 1973). These included (a) decline of other childhood diseases, which allowed more attention to shift to goiter, (b) McClendon's discovery of the relationship between goiter and the iodine content of drinking water, (c) the WWI draft examinations, which revealed the nationwide extent of goiter prevalence, and (d) a large incidence of goiter in Michigan (Levin, 1919).

According to Levin (1919), roughly 24 percent of army recruits from Houghton County, Michigan had simple goiter and 2.4 percent of the men were disqualified for the army based on the size or cystic type of goiter.[6] Dr. David Cowie, of the University of Michigan, became interested in eliminating widespread simple goiter in his home state. Cowie organized a symposium of the Michigan State Medical Society in June 1922, which created the Iodized Salt Committee to explore the feasibility of adding iodine to salt in Michigan. The committee initially entertained the idea of proposing a law

[6]"If these men were considered unacceptable to the US Army because of decreased mentation, inability to complete average mental or physical labor, dyspnea, cardiac, and metabolic abnormalities seen in patients with severe colloid goiter, how useful were they considered in daily functions and work productivity in civilian life?" (Markel, 1987, pg 221)

prohibiting non-iodine fortified salt (Markel, 1987), but they were swayed to allow the profit motives of salt manufacturers to lead them to distribute a product endorsed by medical experts. Introducing iodine to salt was relatively costless as it could be added at the same time as magnesium, which is included to regulate salt flow from the container (Markel, 1987).

Cowie worked with several small salt manufacturers based in Michigan, who were eager to supply a product that they perceived would have a large demand with little extra cost to produce. The Executive Council of the Michigan State Medical Society officially endorsed salt on March 12, 1924 and iodized salt appeared in Michigan groceries on May 1, 1924. The product proved so popular that Morton Salt Company, who initially resisted because of concerns about the high cost of separating a different version of salt for Michigan retailers, began nationwide distribution a few months later. With educational efforts of the Michigan State Medical Society, which gave lectures on the medical benefits of iodized salt and zealous advertisements by salt producers,[7] iodized salt rapidly grew popular. By 1930, iodized salt sales were eight times plain salt sales (Markel, 1987).

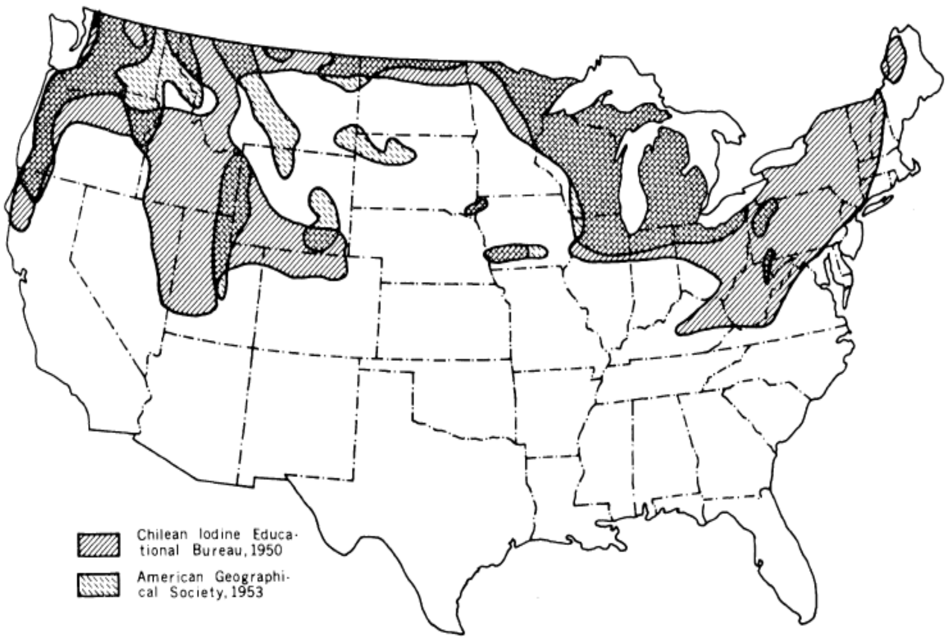
Many later surveys found marked decreases in thyroid enlargement, especially among continuous users of iodized salts. Interestingly, Schiel & Wepfer (1976) found that, among Michigan school children in 1924-51, there was a decline in goiter rates among non-users. Cowie attributed this to ingestion of iodized salt without realizing it, such as in school canteens and restaurants, which seems plausible given that iodized salt made up 90% of salt sales in Michigan at the time (Markel, 1987). This observation alleviates concerns about self-selection into using iodized salt and supports the approximate universality of the intervention. The shaded areas in Figure 2 map the areas with endemic goiter as determined by goiter surveys compiled by the Chilean Iodine Educational Bureau in 1950 and the American Geographical Society in 1953. While it is unclear what definition of endemic goiter was used for these maps, prevalence decreased considerably between the WWI draft era (Figure 1) and 1950, and the diminishing trend continued to 1953.

2.4 Goiter and Confounding Factors

Marine's 1917-19 experiment was the first to inform the US public that iodine supplementation could prevent and treat goiter; hence there is little reason to suspect a *direct* role of iodine in residential selection or selection into iodine-rich diets. Supporting this claim, Figure 1 shows that goiter incidence

[7] Advertisements would often contain phrases such as "Remember, too, that Morton's Iodized Salt protects children against simple goiter - that often unnoticed nutritional disease which is frequently accompanied by underdevelopment, irritability and backwardness at school." (Women's Home Companion, June 1934)

Figure 2: U.S. goiter distribution in the early 1950s



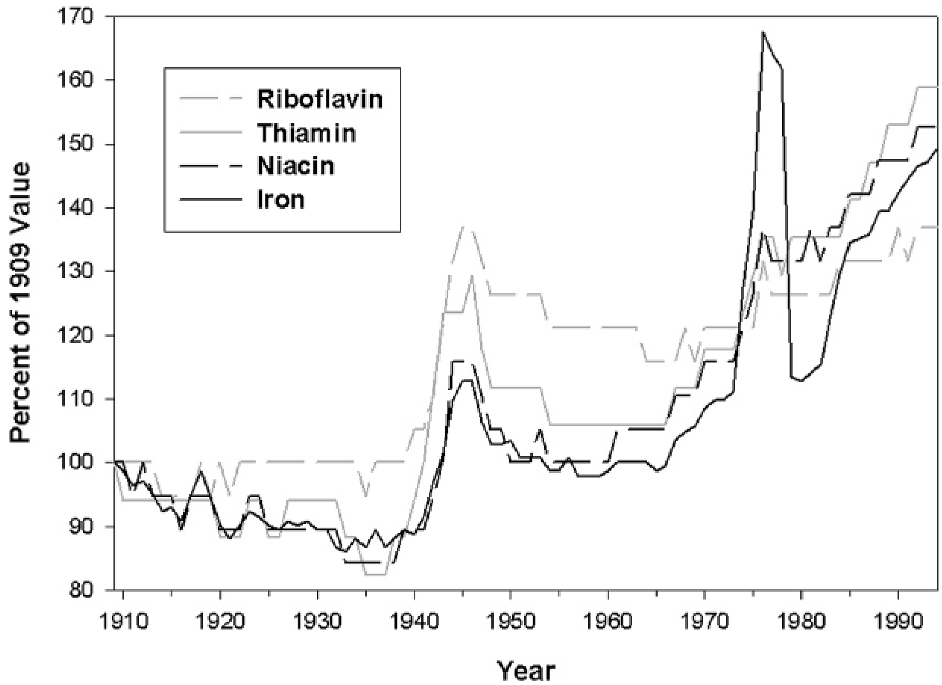
Source: Schiel and Wepfer (1976)

was concentrated in the northern states, which were socioeconomically better off compared to the southern states.

However, one might worry that there may have been other important changes in the US diet, concurrent with the roll out of iodized salt. In fact, food fortification in the US began with salt iodization in 1924, with discoveries of the role of vitamin and mineral deficiencies in many diseases and sicknesses (Backstrand, 2002). However, the knowledge remained mostly in the laboratory until May 1941, when President Roosevelt called a National Nutrition Conference for Defense. Figure 3 shows the change in the per capita riboflavin, iron, niacin, and thiamin contents of American food between 1909 and 1994, which does not coincide with the timing of salt iodization.

Similarly, one might still suspect that high goiter areas prior to iodization were also more likely to have high incidence of other nutrient deficiencies or health issues such as malaria or hookworm. In order to address concerns about the contemporaneous eradication of these infectious diseases, we check the robustness of our main results to controlling for baseline geographic variation in the prevalence of malaria and hookworm, interacted with post-iodization dummies. The robustness of our results alleviates concerns about the geographic pattern of goiter incidence, and hence the pattern of expected benefits from iodized salt, coinciding with the geographic pattern of other health-related improve-

Figure 3: Change in the per capita riboflavin, iron, niacin, and thiamin content of the U.S. food supply between 1909 and 1994



Source: Backstrand (2002)

ments.

3 Data

3.1 Goiter Data

Our information on the geographic distribution of goiter before 1924 comes from the data used to create the first map in Figure 1: medical examinations of over two and a half million drafted men aged 18 to 30 before World War I. Conducted on a large sample of men from all over the United States within a short period of time between 1917 and 1918, these examinations offer a snapshot of the geographic distribution of various mental and physical defects prior to the iodization of salt.[8] Love & Davenport (1920) documents prevalence rates in this sample for over 200 medical conditions, including goiter.

[8]Because this paper focuses on *in utero* exposure to iodine, the ideal dataset would consist of goiter rates from a representative sample of women of childbearing age, instead of men. In the data collected by Olesen (1929), there is a high correlation (0.87) between goiter rates among school-aged girls and boys, which suggests that the distribution of female goiter rates across states should be similar to what is captured by the goiter rates in Love & Davenport (1920), calculated from men of the relevant age range. We do not use the Olesen (1929) goiter rates as our measure of iodine availability because the samples are not representative of each state and numerical rates are only available for 37 states.

In this paper, we use state-level prevalence rates, although rates for smaller regions (collections of counties known as sections) were recorded as well.[9] Table A1 reports for each state the goiter rate recorded in Love & Davenport (1920). The median state-level goiter rate is 0.214% and the maximum is 2.69%.

3.2 Census Data

We also use data from the United States Decennial Census (Ruggles et al., 2015), restricting to individuals born in the twelve-year period spanning 1920 to 1931, which includes the years before, during, and after the nationwide spread of iodized salt. We are interested in labor, education, and marriage outcomes for this cohort in the 1950 to 1980 censuses, during which they were working-aged adults aged 19 to 60.

Individuals are assigned to the goiter rate in their state of birth, which proxies for their risk of being born to an iodine deficient mother. Individuals are also grouped according to their birth year. Those born in the years 1920 to 1923 are marked as "pre-iodization," those born in 1924 to 1927 are classified as born "during iodization," and those born in 1928 to 1931 are considered "post-iodization." Iodized salt first appeared in grocery stores in 1924 and was reported to have generated eight times more sales than regular salt by 1930 (Markel, 1987). In creating the "during" category, we allow four years of leeway following the initial introduction of iodized salt to ensure that the after cohort was exposed to an environment with sufficiently widespread iodized salt availability.

3.2.1 Outcome and Control Variables

We are primarily interested in labor market outcomes. To represent employment, we use two variables: a dummy for labor force participation (which includes job-seekers as participants) and a dummy for employment (which is set to zero for job-seekers). Individuals who report working in the last year also report the number of weeks they worked (in intervals). We create an indicator variable to represent individuals who worked at least 40 weeks to study the intensive margin of labor supply. We also look at total income, which includes income from all sources, including wages and self-employment income. We transform total income using the inverse hyperbolic sine function.[10] For all of these labor

[9] Unfortunately, we cannot use the section-level goiter data because we only have state of birth, not county of birth, for the individuals in our sample.

[10] $\sinh^{-1}(\widehat{\text{Income}}) = \ln(\text{Income} + (\text{Income}^2 + 1)^{1/2})$. The income variable is therefore not conditional on working, and includes zeros for those who do not work.

market variables, we pool individuals from the 1950 to 1980 censuses, during which our sample was aged 19 to 60.

In addition to these labor market outcomes, we also study years of educational attainment, whether an individual has ever been married, and age of first marriage. Because these are all stock variables that are unlikely to be determined in the teenage years or twenties, we only look at individuals in the 1970 and 1980 censuses (when our sample is aged between 39 and 60).

Additional variables taken from the census include gender and race. In addition to including female and black indicator variables as controls, we also control for pre-iodization demographic conditions in the individual's state of birth. This is done by calculating the black and female proportions from the 1920 census in the individual's state of birth. For more details on the construction of variables, see the Data Appendix.

3.2.2 Summary Statistics

Table 1 reports summary statistics for our sample population (individuals born between 1920 and 1931). The first column summarizes our outcome variables for the entire sample, the second restricts to females, and the third focuses on males. Women have much lower labor force participation, labor supply, and income than men. Marriage rates, age at first marriage, and years of schooling are more similar across both genders, although women are more likely to be married and get married slightly earlier.

3.3 Geographic Controls

Because of the clear regional patterns in the distribution of goiter, an important part of our strategy involves allowing for differential birth cohort trends by region. We use the nine Census Bureau divisions, listed in Table A1, to categorize states into regions. Another way we control for regional patterns is by using the average latitude of each individual's state of birth.[11]

3.4 Robustness Check Controls

In our robustness checks, we control for the pre-iodization rates of two other diseases: malaria and hookworm. For malaria, we use the malaria mortality rates from the 1890 Census, used in Bleakley

[11]These numbers were obtained from the online database, MaxMind: `http://dev.maxmind.com/geoip/legacy/codes/state_latlon/`

Table 1: Summary Statistics

	(1) Whole Sample	(2) Females	(3) Males
1950-1980 Censuses			
1(Employed)	0.644	0.429	0.872
	(0.479)	(0.495)	(0.334)
1(Participated in Labor Force)	0.670	0.448	0.905
	(0.470)	(0.497)	(0.293)
1(Worked at least 40 weeks)	0.790	0.659	0.867
	(0.408)	(0.474)	(0.339)
Total Income	19551.4	8690.0	31193.1
	(20266.0)	(12478.3)	(20544.1)
Number of Observations	2383143	1236420	1146723
1970-1980 Censuses			
1(Ever Married)	0.945	0.951	0.937
	(0.229)	(0.216)	(0.242)
Age at First Marriage	22.74	21.43	24.16
	(5.345)	(5.013)	(5.331)
Years of Schooling	11.38	11.31	11.45
	(3.137)	(2.841)	(3.426)
Number of Observations	1789907	930333	859574

Notes: Sample includes all individuals born 1920 to 1931. Statistics are calculated using person-level weights provided by the census. Total income in 1999 dollars.

(2010). Hookworm rates are also taken from Bleakley (2010) and are the same data used by Bleakley (2007). These rates were drawn from around 20,000 recruits in 1917 and 1918, a smaller and separate sample from the recruits tested in Love & Davenport (1920) (Kofoid & Tucker, 1921). Each individual was assigned to the relevant prevalence rates from their state of birth.

In order to allow for differential trends across states that may have been affected differently by the Great Depression, we use state-level unemployment rates calculated from the 1930 census. Similarly, in order to allow for differential trends across states affected differently by the mid-century "Great Migration" of African Americans out of the rural South, we calculate the state-level change, between 1920 and 1940, in the black population share, as well as in the total share of the U.S. population made up by each state, to capture race composition shifts and overall population growth.

We also include years of compulsory schooling as an additional control. We obtained this variable from state-level data used in Lleras-Muney (2002), compiled from multiple sources. This data reports the number of years of required schooling (either by compulsory attendance laws or implied by child labor laws) in each state in each year from 1915 to 1939. Using the same strategy as Lleras-Muney (2002), we match each individual to the law in place in their state of birth in the year they turned 14 (the minimum leaving age across all states and years), as this is arguably the most relevant to their schooling continuation choices.

Finally, we also use WWII state mobilization rates, obtained from Acemoglu et al. (2004). If WWII mobilization had any impact on these individuals, it should have affected them during their young adult or adult life: we therefore use mobilization rates in the individual's state of residence rather than their state of birth.

4 Empirical Strategy

4.1 Overview of strategy

As described in section 2, once Morton Salt Co.'s decision to iodize its supply was made, the spread of iodized salt was wide scale and fairly rapid. Since iodization happened nationwide, incidentally there was no true exclusion from exposure. In the spirit of Bleakley (2010), Hornbeck (2012), and others, our basic strategy is to compare trends in economic outcomes among individuals born in states with different levels of pre-iodization iodine deficiency rates. Feyrer et al. (2017) uses similar strategy to identify the impacts of iodization on recruits' placement into the Army v. the Air Force.

We use the spatial distribution of goiter in 1924 in the continental US to identify differences in pre-iodization deficiency rates. As described in section 3, we use data from the Love & Davenport (1920) survey of military recruits. We link each individual in the census to a goiter rate using their state of birth. We use state of birth to draw focus to the effects of *in utero* exposure to iodine rather than exposure through one's life.

We interpret the goiter value as a proxy for the extent of iodine deficiency in one's state of birth during early life. This proxy will, of course, not fully reflect actual iodine exposure. Nevertheless, as shown in the previous sections, as well as in Feyrer et al. (2017), the spatial distribution of goiter generally mirrors the distribution of iodine content in water sources. While admittedly an imperfect proxy, the distribution allows a rough ordering of individuals according to their exposure to iodine *in utero*.

We study the outcomes of three cohorts: those born before (1920-1923), during (1924-1927), and after (1928-1931) salt iodization. We consider the middle ("during") group because, while the proliferation of iodized salt across the US was rapid, we do not have data on the geographic pattern of this nationwide spread. During the proliferation period, it would be possible to find muted effects simply because iodized salt had not yet reached some markets. To allow for this, we separate the "during" and "after" iodization periods. In the appendix, we show that our results are robust to the use of a more flexible specification that does not rely on this somewhat arbitrary assignment of cohort dummies.

We interpret differences in trends in economic outcomes coincident with the proliferation of iodized salt across individuals born in states with varying pre-iodization levels of goiter as causally related to salt iodization. Because all three cohorts were eventually exposed to iodized salt by late childhood and for the remainder of their lives, we are identifying the impact of differential exposure to iodine specifically *in utero*, which is our primary interest because of the irreversible nature of the cognitive damage that can be caused by lack of iodine during the fetal period. Our estimates are therefore somewhat conservative because they do not consider the potential benefits of increased iodine availability later in life, which all of our cohorts (including our control cohort) may have experienced.

4.2 Specification

The basic difference in differences strategy, then, is to compare the outcomes of cohorts born before to those born during and after iodization, across individuals born in states of varying levels of iodine deficiency. We estimate the following specification, for individual i born in year t in state s (census division d), for outcome y recorded in census year c, where G is the continuous goiter rate, D is a dummy for belonging to the "during" cohort, and A is a dummy for belonging to the "after" cohort:

$$y_{ist} = \beta_1 G_s A_t + \beta_2 G_s D_t + \mu_s + (\zeta_d \text{ x } \delta_t) + (\lambda_c \text{ x } \delta_t) + \eta X_{ist} + \varepsilon_{ist}. \tag{1}$$

Here, β_1 and β_2 are the main coefficients of interest, measuring the difference in birth cohort trends in outcome y across individuals living in states with different levels of iodine deficiency. The specification includes state of birth fixed effects (μ_s) and year of birth fixed effects (δ_t, which are interacted with census waves as well as census divisions) that absorb the main effects of G_s, D_t, and A_t. The census division of birth by birth year interactions (ζ_d x δ_t) is crucial because they control for any regional trends over time that may coincide with the national goiter distribution. By including division-by-birth-year fixed effects, we ensure that we are comparing outcome variable trends (by birth cohort) across high and low goiter states of birth in their deviations from each Census division's average non-linear trend. (λ_c x δ_t) are census wave by birth year interactions, included to account for differential trends in the outcome variables as the cohorts age. Included in X are individual controls for race and gender, as well as controls for the proportion of the population that is female and that is black (measured in 1920) in the individual's state of birth, interacted with the during and after dummies. Finally, we also include average latitude (of the state of birth) interacted with during and after dummies in order to alleviate concerns about differential trends for Northern and Southern states confounding our estimates. Standard errors are clustered at the state of birth level to allow for arbitrary correlation of the errors for individuals born in the same state.

We conduct this analysis on all individuals born between 1920 and 1931, using the 1950 to 1980 censuses. We then look at men and women separately. In order to trace out the effects of salt iodization on labor market outcomes as our cohorts age, we also run these by-gender regressions separately for the 1950-1960 censuses (when our sample was aged 19 to 40) and the 1970-1980 censuses (when they were aged 39 to 60). We test the robustness of our results to the inclusion of controls for contemporaneous disease eradication programs (related to hookworm and malaria), unemployment rates in 1930, demographic changes from 1920 to 1940, compulsory schooling laws, and WWII mobilization rates in an individual's state of residence.

In order to rule out the existence of differential pre-trends across high and low goiter states (which would indicate a potential violation of our difference-in-difference assumptions), we expand our sample to include individuals born in 1916-1919 and run the following regression:

$$y_{ist} = \beta_1 G_s A_t + \beta_2 G_s D_t + \beta_3 G_s P_t + \mu_s + (\zeta_d \text{ x } \delta_t) + (\lambda_c \text{ x } \delta_t) + \eta X_{ist} + \varepsilon_{ist}. \quad (2)$$

Here, P_t represents an indicator variable for those born in the "pre-trend" period (1916-1919). If there were no differential cohort trends across the goiter distribution prior to the introduction of iodized salt, we should be unable to reject the null that β_3 is equal to zero.

5 Results

5.1 Labor Supply and Income

In all of the regressions discussed in this section, our coefficients of interest are the after-by-goiter rate interaction and the during-by-goiter rate interaction: these represent the effect of salt iodization on our outcomes of interest. Although the following tables only report these two coefficients, all specifications also include state of birth fixed effects, year of birth by census wave interactions, census division of birth by birth year interactions, a female dummy, a black dummy, and after and during dummies interacted with average state latitude and 1920 state-level female and black proportions. We multiply each relevant coefficient by the inter-quartile range of the goiter distribution (0.709) to obtain a value that can be interpreted as the effect of moving from a relatively low goiter state (at the 25th percentile) to a high goiter state (at the 75th percentile) when discussing the results.

Table 2 reports the full-sample regression results for our labor outcomes of interest. The effects of salt iodization on the probability of being employed (column 1) and labor force participation (column 2) are both positive and significant, with effect sizes around 0.7 percentage points. We also find that salt iodization increased the likelihood of working at least 40 weeks in the year, conditional on having worked in the last year, by almost one percentage point. In addition, we find an 11% increase in total income.

Our interpretation of these coefficients relies on attributing the change in trends after 1924 to the introduction of iodized salt. If, however, high and low goiter states were trending differently before 1924, this would suggest that the difference in trends after 1924 may not be due to salt iodization. In order to

Table 2: Effects of Salt Iodization on Labor and Income Outcomes

	(1)	(2)	(3)	(4)
	1(Employed)	1(Participated in the Labor Force)	1(Worked at least 40 weeks)	$\sinh^{-1}$(Income)
After x Goiter Rate	0.00707***	0.00680**	0.00877**	0.105***
	(0.00248)	(0.00284)	(0.00371)	(0.0290)
During x Goiter Rate	0.00355	0.00323	0.00848***	0.0267
	(0.00231)	(0.00233)	(0.00268)	(0.0259)
Observations	2383143	2383143	1537003	2135396
Mean of Dep. Var.	0.644	0.670	0.790	7.902

Notes: Standard errors, clustered by state of birth, in parentheses (*** p<0.01, ** p<0.05, * p<0.1). Goiter Rate is the goiter rate in the individual's state of birth from Love and Davenport (1920), scaled by the difference between the 75th and 25th percentile of the goiter distribution (0.71). After is a dummy equal to 1 for those born 1928-1931. During is a dummy equal to 1 for those born 1924-1927. These regressions use the 1950 to 1980 censuses, restricting to individuals born in 1920-1931. All regressions include state of birth fixed effects, year of birth x census year dummies, census division of birth x birth year dummies, gender, race, and During and After dummies interacted with average state latitude and 1920 state-level female and black proportions. $\sinh^{-1}$(Income) takes the inverse hyperbolic sine of total incomeweeks, including zeros for those not working.

Table 3: Pre-Trends in Labor and Income Outcomes

	(1)	(2)	(3)	(4)
	1(Employed)	1(Participated in the Labor Force)	1(Worked at least 40 weeks)	$\sinh^{-1}$(Income)
After x Goiter Rate	0.00707***	0.00680**	0.00880**	0.107***
	(0.00248)	(0.00284)	(0.00370)	(0.0288)
During x Goiter Rate	0.00356	0.00323	0.00854***	0.0274
	(0.00231)	(0.00233)	(0.00269)	(0.0259)
Pre-Trend x Goiter Rate	-0.00317	-0.00264	-0.00422	0.0107
	(0.00210)	(0.00183)	(0.00370)	(0.0253)
Observations	3114884	3114884	1940335	2784412
Mean of Dep. Var.	0.635	0.660	0.794	7.930

Notes: Standard errors, clustered by state of birth, in parentheses (*** p<0.01, ** p<0.05, * p<0.1). Goiter Rate is the goiter rate in the individual's state of birth from Love and Davenport (1920), scaled by the difference between the 75th and 25th percentile of the goiter distribution (0.71). Pre-Trend is a dummy equal to 1 for those born 1916-1919. After is a dummy equal to 1 for those born 1928-1931. During is a dummy equal to 1 for those born 1924-1927. These regressions use the 1950 to 1980 censuses, restricting to individuals born in 1916-1931. All regressions include state of birth fixed effects, year of birth x census year dummies, census division of birth x birth year dummies, gender, race, and Pre-Trend, During, and After dummies interacted with average state latitude and 1920 state-level female and black proportions. $\sinh^{-1}$(Income) takes the inverse hyperbolic sine of total income, including zeros for those not working.

test for the existence of differential pre-trends, we run the regression specified in equation 2, including cohorts born in an even earlier period: 1916 to 1919. Results are reported in Table 3, where the pre-trend-by-goiter coefficient estimates the difference across the goiter distribution in cohort trends prior to the introduction of iodized salt. Across all specifications, these pre-trend coefficients are smaller in magnitude than both the during and after coefficients and not significantly different from zero. This alleviates concerns that states were experiencing different cohort trends – before 1924 – systematically correlated with the goiter distribution. Moreover, the during-by-goiter and after-by-goiter coefficient estimates are almost identical to those in the previous table.

5.1.1 Gender Heterogeneity

We next ask whether this cognitive shock impacted labor market outcomes differently for men and women. Table 4 reports the results of two separate regressions: one for women (Panel A) and one for men (Panel B), along with the difference in our main coefficients across the two specifications (Panel C). Stark gender differences are apparent. All of the positive effects on labor supply and income, reported in the previous tables, are driven by women. In fact, there are no significant coefficients in the male regressions, and for labor force participation and income, the after interaction coefficients are significantly larger for women than for men. These results are consistent with the hypothesis that female fetuses are more sensitive to maternal thyroid deficiency than male fetuses, for which supporting evidence exists in both the economic and biological literature (Field et al., 2009; Friedhoff et al., 2000). Comparing the dependent variable means for men and women, it is also clear that women have much lower labor supply and income than men during this period, implying much larger scope for improvement in all of these outcomes.

The next table breaks our sample down even further in order to study how the effects of salt iodization may have differed over the course of these individuals' careers. In particular, we are interested in comparing effects in young adulthood and prime ages to effects in later adulthood. Focusing on women, who were the only ones significantly impacted by salt iodization, we run our labor market outcome regressions using only the 1950 and 1960 censuses (during which our sample individuals were aged 19 to 40) and then using only the 1970 and 1980 censuses (during which they were 39 to 60 years old). Table 5 reports these regressions in Panels A and B, respectively, and reveals a clear pattern. The effects of salt iodization on labor supply and income seem to be entirely driven by the

Table 4: Effects of Salt Iodization on Labor and Income Outcomes, By Gender

	(1)	(2)	(3)	(4)
	1(Employed)	1(Participated in the Labor Force)	1(Worked at least 40 weeks)	$sinh^{-1}$(Income)
Panel A: Females				
After x Goiter Rate	0.0108***	0.0121***	0.0144***	0.149***
	(0.00360)	(0.00395)	(0.00525)	(0.0505)
During x Goiter Rate	0.00519	0.00579	0.0206***	0.0192
	(0.00372)	(0.00405)	(0.00466)	(0.0398)
Observations	1236420	1236420	606704	1108650
Mean of Dep. Var.	0.429	0.448	0.659	5.586
Panel B: Males				
After x Goiter Rate	0.00197	0.000148	0.00562	0.0288
	(0.00392)	(0.00364)	(0.00443)	(0.0173)
During x Goiter Rate	0.000934	-0.000487	0.000888	0.0116
	(0.00237)	(0.00247)	(0.00384)	(0.0240)
Observations	1146723	1146723	930299	1026746
Mean of Dep. Var.	0.872	0.905	0.867	10.38
Panel C: Female-Male Difference				
After x Goiter Rate	0.00884	0.0119**	0.00874	0.120**
	(0.00576)	(0.00521)	(0.00592)	(0.0504)
During x Goiter Rate	0.00425	0.00628	0.0197***	0.00759
	(0.00464)	(0.00516)	(0.00658)	(0.0424)

Notes: Standard errors, clustered by state of birth, in parentheses (*** p<0.01, ** p<0.05, * p<0.1). Goiter Rate is the goiter rate in the individual's state of birth from Love and Davenport (1920), scaled by the difference between the 75th and 25th percentile of the goiter distribution (0.71). After is a dummy equal to 1 for those born 1928-1931. During is a dummy equal to 1 for those born 1924-1927. These regressions use the 1950 to 1980 censuses, restricting to individuals born in 1920-1931. All regressions include state of birth fixed effects, year of birth x census year dummies, census division of birth x birth year dummies, gender, race, and During and After dummies interacted with average state latitude and 1920 state-level female and black proportions. $sinh^{-1}$(Income) takes the inverse hyperbolic sine of total income, including zeros for those not working.

Table 5: Effects of Salt Iodization on Female Labor and Income Outcomes in Early and Late Censuses

	(1)	(2)	(3)	(4)
	1(Employed)	1(Participated in the Labor Force)	1(Worked at least 40 weeks)	$\sinh^{-1}$(Income)
Panel A: 1950-1960 Censuses (Ages 19 to 40)				
After x Goiter Rate	0.0185***	0.0221***	0.0288***	0.241**
	(0.00593)	(0.00657)	(0.0106)	(0.100)
During x Goiter Rate	0.0133**	0.0135*	0.0426***	0.0309
	(0.00631)	(0.00695)	(0.0111)	(0.0761)
Observations	306087	306087	80777	180375
Mean of Dep. Var.	0.357	0.374	0.568	4.534
Panel B: 1970-1980 Censuses (Ages 39 to 60)				
After x Goiter Rate	0.00266	0.00152	0.00286	0.0604*
	(0.00330)	(0.00329)	(0.00405)	(0.0327)
During x Goiter Rate	-0.00346	-0.00254	0.00218	0.00762
	(0.00265)	(0.00278)	(0.00457)	(0.0337)
Observations	930333	930333	525927	928275
Mean of Dep. Var.	0.505	0.526	0.736	6.701

Notes: Standard errors, clustered by state of birth, in parentheses (*** p<0.01, ** p<0.05, * p<0.1). Goiter Rate is the goiter rate in the individual's state of birth from Love and Davenport (1920), scaled by the difference between the 75th and 25th percentile of the goiter distribution (0.71). After is a dummy equal to 1 for those born 1928-1931. During is a dummy equal to 1 for those born 1924-1927. These regressions restrict to women born in 1920-1931. All regressions include state of birth fixed effects, year of birth x census year dummies, census division of birth x birth year dummies, gender, race, and During and After dummies interacted with average state latitude and 1920 state-level female and black proportions. $\sinh^{-1}$(Income) takes the inverse hyperbolic sine of total income, including zeros for those not working.

large impact salt iodization had on women early in their careers. For all outcomes, the early census coefficients are larger in magnitude than the late census coefficients. With the exception of income – for which we see a marginally significant 6% increase even in later census waves – none of the late census coefficients are significantly different from zero. This positive shock to cognitive ability appears to have made women more employable and increased their earning potential early in their careers. Later in life, these women may have gotten married and dropped out of the labor force (as a result of higher-earning husbands or family responsibilities), leaving them no more likely to be employed than their unaffected counterparts. In the appendix, Table A2 reveals no effects for men in either census wave pair, with the exception of a small income increase of 2% in later census waves (significant at the 10% level), much smaller than the female income effects.

5.2 Robustness

There are a number of reasons why trends in labor market outcomes across birth cohorts in the 1920's might differ across states. In order to interpret the coefficients discussed above as causal estimates of the effect of iodized salt specifically, we must assume that any other drivers of these differential birth cohort trends across states are uncorrelated with the distribution of goiter. A violation of this assumption means that we are omitting important variables that are potentially correlated with our outcomes of interest as well as our after-by-goiter and during-by-goiter interactions. To rule out alternative explanations for the effects that we find, we control for a number of important events or policies that could have potentially affected the state-specific trends in outcomes across our before, during, and after cohorts.

First, we consider contemporaneous health improvements, such as the eradication or treatment of diseases, which occurred roughly contemporaneously to the roll out of iodized salt. In particular, malaria and hookworm eradication programs, both concentrated in the South, took place in the decades immediately before and during the spread of iodized salt. Malaria eradication programs started in the 1920's, while the hookworm eradication campaign began around 1910. The correlation between early 1900's goiter prevalence and malaria and hookworm rates are weak and negative (-0.33 and -0.35, respectively) and thus unlikely to be driving our results. We validate this, however, by including controls for pre-iodization prevalence rates of malaria and hookworm, interacted with the during and after dummies.

Table 6: Effects of Salt Iodization on Labor and Income Outcomes, By Gender, with Additional Controls

	(1)	(2)	(3)	(4)
	1(Employed)	1(Participated in the Labor Force)	1(Worked at least 40 weeks)	$\sinh^{-1}$(Income)
Panel A: Females				
After x Goiter Rate	0.0165***	0.0187***	0.0176**	0.201***
	(0.00408)	(0.00432)	(0.00692)	(0.0607)
During x Goiter Rate	0.0109**	0.0126***	0.0281***	0.0914*
	(0.00450)	(0.00455)	(0.00631)	(0.0455)
Observations	1179112	1179112	574618	1052355
Mean of Dep. Var.	0.425	0.445	0.657	5.558
Panel B: Males				
After x Goiter Rate	-0.00428	-0.00603	0.00725	0.0228
	(0.00444)	(0.00414)	(0.00480)	(0.0264)
During x Goiter Rate	-0.00239	-0.00436	-0.00333	0.00763
	(0.00292)	(0.00267)	(0.00339)	(0.0266)
Observations	1092150	1092150	879680	973193
Mean of Dep. Var.	0.871	0.904	0.865	10.36
Panel C: Female-Male Difference				
After x Goiter Rate	0.0208***	0.0247***	0.0104	0.178***
	(0.00683)	(0.00613)	(0.00798)	(0.0622)
During x Goiter Rate	0.0133**	0.0170***	0.0314***	0.0838
	(0.00625)	(0.00626)	(0.00666)	(0.0520)
Additional Controls	state-of-birth hookworm and malaria prevalence rates (interacted with During and After), state-of-birth compulsory schooling requirements at age 14, state-of-residence WWII mobilization rates, state-of-birth unemployment rates in 1930 (interacted with During and After), state-of-birth change in black population share from 1920 to 1940 (interacted with Durng and After), state-of-birth change in the total share of US population living in state from 1920 to 1940 (interacted with During and After)			

Notes: Standard errors, clustered by state of birth, in parentheses (*** p<0.01, ** p<0.05, * p<0.1). Goiter Rate is the goiter rate in the individual's state of birth from Love and Davenport (1920), scaled by the difference between the 75th and 25th percentile of the goiter distribution (0.71). After is a dummy equal to 1 for those born 1928-1931. During is a dummy equal to 1 for those born 1924-1927. These regressions use the 1950 to 1980 censuses, restricting to individuals born in 1920-1931. All regressions include state of birth fixed effects, year of birth x census year dummies, census division of birth x birth year dummies, gender, race, and During and After dummies interacted with average state latitude and 1920 state-level female and black proportions. $\sinh^{-1}$(Income) takes the inverse hyperbolic sine of total income, including zeros for those not working.

We also address the possibility that changes in compulsory schooling laws, implemented at different times across states, resulted in differential trends in labor outcomes, which we are attributing to introduction of iodized salt. We use data collected by Lleras-Muney (2002), which records the minimum years of schooling required by law in each state from 1915 to 1939. Like Lleras-Muney (2002), we match each individual to the compulsory schooling laws in place in their state of birth at age 14 (the lowest minimum leaving age across all states). For the analysis discussed here, we use the number of years of school required according to compulsory attendance laws, although the results are similar when we use the number of years required according to child labor laws.

It is also well-documented that state mobilization rates for World War II affected labor force participation, particularly for females during this period (Acemoglu et al., 2004). To control for this, we use the state-level mobilization rate in an individual's state of residence from Acemoglu et al. (2004).

Finally, all of our sample individuals either lived through the Great Depression or its immediate aftermath, but the before, during, and after cohorts were exposed at different points in their life, which could have had important implications for the severity of the long-term impact on each cohort. If, in addition, the Great Depression hit some states harder than others, it becomes another potential reason for differential birth cohort trends across states. In order to proxy for a state's economic conditions during the Great Depression, we calculate state-level unemployment rates from the 1930 census.[12] We match this to individuals using their state of birth and control for the interaction with during and after dummies.

We use a similar strategy to address concerns that the Great Migration could have also resulted in the differential cohort trends that we are attributing to the iodization of salt. During the childhood years of our sample cohort, many of these individuals were exposed to large shares of African Americans either moving out of or moving into their communities. To rule out the possibility that these demographic shifts are driving our results above, we allow for differential trends across states that experienced different racial composition changes and different levels of population growth between 1920 and 1940, two decades of substantial migration that coincided with the childhood years of our cohorts. Specifically, we include During and After interactions with the following two variables: the 1920 to 1940 change in the black population share in an individual's state of birth and the 1920 to 1940 change in the share of the total U.S. population living in an individual's state of birth.

Table 6 reports the results of regressions that control for all of the potential confounders just dis-

[12]Unemployment rates are not available in the 1920 census.

cussed. The first panel reports the results for women and the second panel reports the results for men. Across all outcomes and samples, we find very similar results: positive and significant effects on female labor supply and income, but no effects on male outcomes.

The appendix contains additional robustness checks, where we account for mean reversion (Table A4), show that the Dust Bowl was not an important confounder (Table A5), and allow for a more flexible specification that does not rely on our arbitrary definitions of the During and After cohorts (Figures A1A to A1D).

We also show that increased access to iodine did not affect the mortality rates of our cohorts, which alleviates concerns about our results being driven by a changing sample composition induced by differential mortality. Table A3 shows no differential trends across the goiter distribution in terms of cohort size or cohort gender composition.

5.3 Additional Outcomes

Table 7: Effects of Salt Iodization on Female Education and Marital Outcomes

	(1)	(2)	(3)
	Years of Schooling	1(Ever Married)	Age at First Marriage
After x Goiter Rate	0.0712*	0.000541	0.232***
	(0.0379)	(0.00182)	(0.0478)
During x Goiter Rate	0.0359	0.000702	0.0394
	(0.0274)	(0.00191)	(0.0543)
Observations	930333	930333	761885
Mean of Dep. Var.	11.31	0.951	21.43

Notes: Standard errors, clustered by state of birth, in parentheses (*** p<0.01, ** p<0.05, * p<0.1). Goiter Rate is the goiter rate in the individual's state of birth from Love and Davenport (1920), scaled by the difference between the 75th and 25th percentile of the goiter distribution (0.71). After is a dummy equal to 1 for those born 1928-1931. During is a dummy equal to 1 for those born 1924-1927. These regressions use the 1970 to 1980 censuses, restricting to women born in 1920-1931. All regressions include state of birth fixed effects, year of birth x census year dummies, census division of birth x birth year dummies, gender, race, and During and After dummies interacted with average state latitude and 1920 state-level female and black proportions.

Having established that improved access to iodine substantially improved female labor market outcomes, we next study the effects of this cognitive shock on other dimensions of women's lives. Table 7 reports the results of our main regressions on female educational attainment and marriage outcomes, restricting to the 1970-1980 census waves in order to focus on a sample of women old enough to have completed their schooling and likely to have made their first marriage decisions.

First, we ask whether educational attainment was an important mechanism behind the positive labor market effects of improved cognitive ability. Column 1 of Table 7 suggests that it was not. Although the after-by-goiter coefficient is positive and statistically significant, the magnitude of this coefficient is small, translating to about 2 weeks of school, much too small to be generating the large effects on income reported in Table 5. It should be noted that in a standard model of educational attainment (Card, 2001), a positive shock to the ability endowment can lead to either an increase or a decrease in educational attainment because it can raise the returns to education as well as the initial wage earned (without any education).[13] In this case, these two opposing effects appear to almost cancel each other out, leading to a small but significant increase in average educational attainment. For men, as we report in Appendix Table A6, the coefficient estimates are also small in magnitude and not significantly different from the female coefficients.

Next, we ask whether changes in labor market outcomes were accompanied by changes in marital decisions. Increased iodine availability does not appear to have affected overall ever-married rates, which is unsurprising given that 95% of this sample of women has been married at least once. However, this cognitive shock does appear to have resulted in delays in marriage: we estimate a small but statistically significant increase in the age at first marriage of approximately a quarter of a year. Similar to the other outcomes discussed previously, we find no significant effects on men's marital decisions, as shown in Appendix Table A6.

6 Conclusion

In this study, we document the effects of the rapid nationwide iodization of salt in the United States. We estimate substantial impacts on employment, labor force participation, and incomes. The impacts are strongest for, indeed driven nearly entirely by, women. We also find that employment impacts are strong in young adulthood and at prime ages, but grow weaker as treated women grow older. Additional results show that impacted women marry at later ages, consistent with treated new labor force entrants transitioning out of the work force at later ages to raise families.

[13] If the ability endowment shock increases the initial wage regardless of education and the return to education is relatively low, then lifetime income can increase with lower schooling. If there is disutility associated with schooling then there is further downward pressure on educational attainment.

Our results contribute to several strands of literature and current policy debates. First, this study contributes to the growing literature on the long-term effects of early-life conditions, particularly the smaller set of recent work, estimating gains to purposeful and beneficial large-scale policy interventions like fortification schemes. These results differ from earlier studies of early-life "shocks" in that they validate the impacts of actionable policies which can then be reproduced elsewhere. In this way, the study of historic successes, and failures for that matter, in the US and other developed settings, can potentially provide important predictions for academic researchers and policy-makers faced with similar issues in developing countries today.

Second, while previous studies have estimated the roles of historical events, such as World War II and the staged rise in access to contraception, in explaining increases in labor force participation among women (e.g. Goldin (1991), Goldin & Olivetti (2013), Goldin & Katz (2002), and Bailey (2006)), we contribute complementary evidence that salt iodization explains a rise of 2.21 percentage points in early censuses (roughly 6 percent of the total rise from 1950 to 1990). Our evidence pertains to cohorts born after those most affected by the war, but before those most affected by increased access to oral contraceptives.[14] Unlike for these previously studied events, impacts on participation of salt iodization are not focused on higher-educated women but prevail despite negligible impacts on schooling completion.

Additionally, our study provides evidence of the magnitude of benefits from eradication of deficiencies in essential micronutrients such as iodine. Many developing country populations face myriad nutritional constraints, which have long-lasting impacts on health, economic livelihoods, and general welfare. Our estimates show that salt iodization led to a roughly 1.21 percentage point rise in female labor force participation. From a base labor force of 13 million women in 1940 (Durand & Goldfield, 1944), this amounts to almost 2 billion USD in additional income using the mean income for the female sample inflated to 2016 dollars (13 million x 0.0121 x 12,514 USD = 1.97 billion USD).[15]

Lastly, it should be noted that the "intervention" cost the taxpayer nothing, in that the roll-out of iodized salt was completely undertaken by the private sector. That is, the cost of salt iodization was fully borne by the salt producer, while the cognitive benefit was realized by the general population. We conjecture that the rapid rise in both supply and demand might be attributable to the efficiency and underlying profit motive of the private firm that undertook the intervention.

[14] Indeed, we estimate our rise in labor force participation due to salt iodization *relative* to the cohort affected by the war.

[15] This calculation does not take into account the value of home production, which could have decreased with more women entering the labor force.

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A Additional Tables

In Table A1, we list all states (excluding Hawaii) by Census division, along with their corresponding goiter rates from Love & Davenport (1920).

Table A1: Regional Classification of States

Census Division	State	Love and Davenport (1920) Goiter Rate *(ppt)*
New England	Connecticut	0.089
New England	Maine	0.066
New England	Massachusetts	0.032
New England	New Hampshire	0.070
New England	Rhode Island	0.055
New England	Vermont	0.214
Middle Atlantic	New Jersey	0.043
Middle Atlantic	New York	0.119
Middle Atlantic	Pennsylvania	0.410
East North Central	Illinois	0.779
East North Central	Indiana	0.649
East North Central	Michigan	1.143
East North Central	Ohio	0.559
East North Central	Wisconsin	1.402
West North Central	Iowa	0.668
West North Central	Kansas	0.125
West North Central	Minnesota	0.804
West North Central	Missouri	0.399
West North Central	Nebraska	0.214
West North Central	North Dakota	0.873
West North Central	South Dakota	0.409
South Atlantic	Delaware	0.059
South Atlantic	District of Columbia	0.139
South Atlantic	Florida	0.025
South Atlantic	Georgia	0.052
South Atlantic	Maryland	0.094
South Atlantic	North Carolina	0.181
South Atlantic	South Carolina	0.094
South Atlantic	Virginia	0.338
South Atlantic	West Virginia	0.789
East South Central	Alabama	0.056
East South Central	Kentucky	0.141
East South Central	Mississippi	0.064
East South Central	Tennessee	0.196
West South Central	Arkansas	0.040
West South Central	Louisiana	0.062
West South Central	Oklahoma	0.072
West South Central	Texas	0.030
Mountain	Arizona	0.121
Mountain	Colorado	0.529
Mountain	Idaho	2.691
Mountain	Montana	2.100
Mountain	Nevada	0.638
Mountain	New Mexico	0.088
Mountain	Utah	1.572
Mountain	Wyoming	1.537
Pacific	Alaska	1.314
Pacific	California	0.445
Pacific	Oregon	2.631
Pacific	Washington	2.340

Table A2 reports the results of our labor regressions on men, separately for early and late census waves.

Table A2: Effects of Salt Iodization on Male Labor and Income Outcomes in Early and Late Censuses

	(1)	(2)	(3)	(4)
	1(Employed)	1(Participated in the Labor Force)	1(Worked at least 50 weeks)	$\sinh^{-1}$(Income)
Panel A: 1950-1960 Censuses (Ages 19 to 40)				
After x Goiter Rate	0.00385	0.00377	0.00862	0.0350
	(0.00660)	(0.00588)	(0.00816)	(0.0355)
During x Goiter Rate	0.000883	0.000452	-0.00239	-0.00530
	(0.00421)	(0.00427)	(0.00749)	(0.0450)
Observations	287149	287149	162305	170601
Mean of Dep. Var.	0.874	0.912	0.818	9.870
Panel B: 1970-1980 Censuses (Ages 39 to 60)				
After x Goiter Rate	0.000334	-0.00332	0.00137	0.0211
	(0.00263)	(0.00274)	(0.00184)	(0.0127)
During x Goiter Rate	0.00115	-0.00140	0.00303	0.0263*
	(0.00238)	(0.00231)	(0.00182)	(0.0140)
Observations	859574	859574	767994	856145
Mean of Dep. Var.	0.870	0.898	0.920	10.93

Notes: Standard errors, clustered by state of birth, in parentheses (*** p<0.01, ** p<0.05, * p<0.1). Goiter Rate is the goiter rate in the individual's state of birth from Love and Davenport (1920), scaled by the difference between the 75th and 25th percentile of the goiter distribution (0.71). After is a dummy equal to 1 for those born 1928-1931. During is a dummy equal to 1 for those born 1924-1927. These regressions restrict to men born in 1920-1931. All regressions include state of birth fixed effects, year of birth x census year dummies, census division of birth x birth year dummies, gender, race, and During and After dummies interacted with average state latitude and 1920 state-level female and black proportions. $\sinh^{-1}$(Income) takes the inverse hyperbolic sine of total income, including zeros for those not working.

In order to assess whether the increased availability of iodine affected mortality, we take all individuals born between 1920 and 1931 in the 1940 census (the first census to record all of our birth cohorts of interest) and collapse to the birth-year birth-state level, counting the total number of individuals as well as calculating the male fraction of each cohort. If salt iodization affected mortality, we would expect to see effects on cohort size. We might also see effects on the male fraction because male fetuses are more vulnerable *in utero* (Cagnacci et al., 2004; Sanders & Stoecker, 2015; Trivers & Willard, 1973). We therefore regress cohort size and the male proportion on our after-by-goiter and during-by-goiter variables of interest, controlling for birth state and birth year fixed effects, along with after and during dummies interacted with state latitude and 1920 female and black proportions. We find no differential changes across the goiter distribution in cohort size or gender composition after the introduction of iodized salt. None of the coefficients in Table A3 are significantly different from zero (in terms of magnitude, they are at most a few hundredths of a standard deviation), suggesting that salt iodization did not affect our sample composition.

Table A3: Salt Iodization and Cohort Composition

	(1)	(2)
	Cohort Size	Fraction Male
After x Goiter Rate	525.7	0.00602
	(416.1)	(0.00619)
During x Goiter Rate	-146.4	-0.0330
	(316.5)	(0.0217)
Observations	596	596
Mean of Dep. Var.	46912.7	0.495
Standard Deviation of Dep. Var.	43529.8	0.0660

Notes: Standard errors, clustered by state, in parentheses (*** p<0.01, ** p<0.05, * p<0.1). Each observation represents a birth-state birth-year combination. Goiter Rate is the goiter rate in the individual's state of birth from Love and Davenport (1920), scaled by the difference between the 75th and 25th percentile of the goiter distribution (0.71). After is a dummy equal to 1 for birth years 1928-1931. During is a dummy equal to 1 for birth years 1924-1927. These regressions use the 1940 census, restricting to birth years 1920-1931. All regressions include During and After dummies interacted with average state latitude and 1920 state-level female and black proportions.

Table A4 addresses the concern that mean reversion could be driving our results, by allowing for differential cohort trends across areas with varying levels of the dependent variable at baseline. To allow for these trends, the ideal strategy would involve including interactions between our During and After dummies and state-level averages of each of our dependent variables from a baseline year. In our case, 1920 is the obvious choice, as this is the year of the census that immediately preceded salt iodization. Unfortunately, the 1920 census did not collect data on almost all of our dependent variables, with the exception of labor force participation. Therefore, for the majority of our regressions, we use 1920 state-level averages of the closest proxy available. To proxy for employment and weeks worked, we use labor force participation. For income, we use the occupation score, a score given to each individual based on their occupation, where higher scores represent occupations with higher median income (based on 1950's income and occupation data). Because we run our regressions separately for men and women, we calculate these state-level averages by gender and use the relevant gender-specific values in each gender-specific regression. In Table A4, it is clear that including these mean reversion controls (1920 state-level averages interacted with During and After dummies) has no effect on our main results.

Table A4: Effects of Salt Iodization on Labor and Income Outcomes, By Gender, Accounting for Mean Reversion

	(1)	(2)	(3)	(4)
	1(Employed)	1(Participated in the Labor Force)	1(Worked at least 40 weeks)	$\sinh^{-1}$(Income)
Panel A: Females				
After x Goiter Rate	0.0113***	0.0128***	0.0128**	0.150***
	(0.00374)	(0.00413)	(0.00558)	(0.0510)
During x Goiter Rate	0.00585	0.00662	0.0212***	0.0240
	(0.00389)	(0.00421)	(0.00467)	(0.0392)
Observations	1236420	1236420	606704	1108650
Mean of Dep. Var.	0.429	0.448	0.659	5.586
Panel B: Males				
After x Goiter Rate	0.00247	0.000325	0.00582	0.0296
	(0.00411)	(0.00382)	(0.00459)	(0.0185)
During x Goiter Rate	0.00118	-0.0000895	0.000862	0.0127
	(0.00269)	(0.00279)	(0.00395)	(0.0229)
Observations	1146723	1146723	930299	1026746
Mean of Dep. Var.	0.872	0.905	0.867	10.38
Panel C: Female-Male Difference				
After x Goiter Rate	0.00884	0.0124**	0.00702	0.120**
	(0.00578)	(0.00518)	(0.00650)	(0.0514)
During x Goiter Rate	0.00467	0.00671	0.0204***	0.0113
	(0.00489)	(0.00532)	(0.00660)	(0.0400)

Notes: Standard errors, clustered by state of birth, in parentheses (*** p<0.01, ** p<0.05, * p<0.1). Goiter Rate is the goiter rate in the individual's state of birth from Love and Davenport (1920), scaled by the difference between the 75th and 25th percentile of the goiter distribution (0.71). After is a dummy equal to 1 for those born 1928-1931. During is a dummy equal to 1 for those born 1924-1927. These regressions use the 1950 to 1980 censuses, restricting to individuals born in 1920-1931. All regressions include state of birth fixed effects, year of birth x census year dummies, census division of birth x birth year dummies, gender, race, and During and After dummies interacted with average state latitude and 1920 state-level female and black proportions. $\sinh^{-1}$(Income) takes the inverse hyperbolic sine of total income, including zeros for those not working. All regressions control for mean reversion by interacting 1920 state-level averages of the dependent variable (or its closest available proxy) with During and After dummies.

The Dust Bowl was another event that roughly coincided with the introduction of iodized salt. In the 1930's, large dust storms in the Great Plains states caused massive soil erosion and reduced agricultural land values in highly eroded areas (Hornbeck, 2012), which could have resulted in differential cohort trends that we might be incorrectly attributing to salt iodization. Because the negative effects of the Dust Bowl were felt almost exclusively by a limited number of geographically concentrated states, we can check to see whether this event was a potential confounder by excluding these states from our sample and repeating our analysis. Table A5 reports the results of this exercise, excluding individuals born in the Great Plains and neighboring states (Arkansas, Colorado, Iowa, Kansas, Louisiana, Minnesota, Missouri, Montana, Nebraska, New Mexico, North Dakota, Oklahmoa, South Dakota). These results lead us to the same conclusions as before, implying that the Dust Bowl was not the reason for the results we find.

Table A5: Effects of Salt Iodization on Labor and Income Outcomes, By Gender, Excluding Dust Bowl States

	(1)	(2)	(3)	(4)
	1(Employed)	1(Participated in the Labor Force)	1(Worked at least 40 weeks)	$\sinh^{-1}$(Income)
Panel A: Females				
After x Goiter Rate	0.0116***	0.0137***	0.0163*	0.217***
	(0.00402)	(0.00434)	(0.00807)	(0.0512)
During x Goiter Rate	0.0102**	0.0105**	0.0202***	0.0532
	(0.00428)	(0.00456)	(0.00644)	(0.0522)
Observations	938025	938025	460665	840341
Mean of Dep. Var.	0.435	0.455	0.667	5.660
Panel B: Males				
After x Goiter Rate	0.00234	0.000359	0.00688	0.0207
	(0.00487)	(0.00474)	(0.00484)	(0.0147)
During x Goiter Rate	0.000571	-0.000963	0.00102	0.0104
	(0.00367)	(0.00383)	(0.00498)	(0.0312)
Observations	869965	869965	704195	778417
Mean of Dep. Var.	0.870	0.904	0.867	10.38
Panel C: Female-Male Difference				
After x Goiter Rate	0.00928	0.0134**	0.00939	0.197***
	(0.00612)	(0.00544)	(0.00891)	(0.0527)
During x Goiter Rate	0.00961	0.0115*	0.0192*	0.0428
	(0.00618)	(0.00675)	(0.00943)	(0.0606)

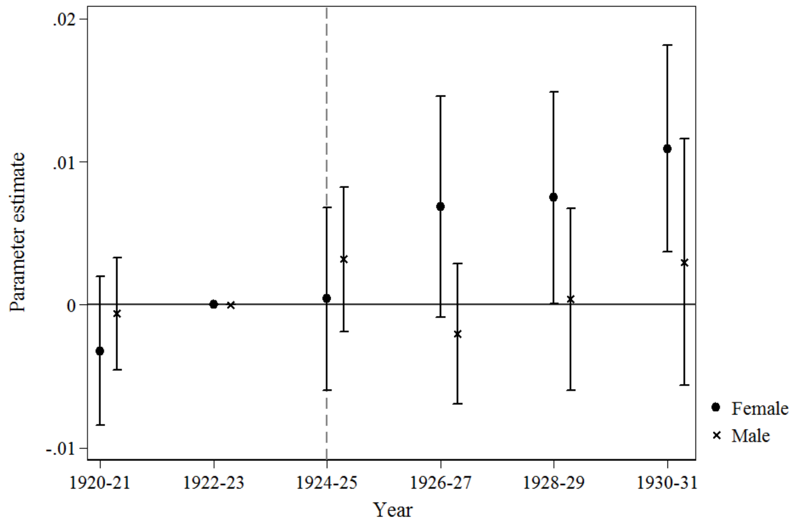
Notes: Standard errors, clustered by state of birth, in parentheses (*** p<0.01, ** p<0.05, * p<0.1). Goiter Rate is the goiter rate in the individual's state of birth from Love and Davenport (1920), scaled by the difference between the 75th and 25th percentile of the goiter distribution (0.71). After is a dummy equal to 1 for those born 1928-1931. During is a dummy equal to 1 for those born 1924-1927. These regressions use the 1950 to 1980 censuses, restricting to individuals born in 1920-1931 and excluding individuals born in Arkansas, Colorado, Iowa, Kansas, Louisiana, Minnesota, Missouri, Montana, Nebraska, New Mexico, North Dakota, Oklahmoa, South Dakota, Texas, and Wyoming. All regressions include state of birth fixed effects, year of birth x census year dummies, census division of birth x birth year dummies, gender, race, and During and After dummies interacted with average state latitude and 1920 state-level female and black proportions. $\sinh^{-1}$(Income) takes the inverse hyperbolic sine of total income, including zeros for those not working.

Figures A1A to A1D illustrate the results from a more flexible specification that does not rely on the arbitrary classification of cohorts into before, during, or after iodization. In this specification, we replace our during-by-goiter-rate and after-by-goiter-rate interactions with indicator variables for each two-year period from 1920 to 1931 (interacted with goiter rate). The years 1922-1923 (immediately before salt iodization) are the omitted category. Figures A1A to A1D report the coefficient estimates and 90% confidence intervals for each of these interactions, separately for men and women, for each of our labor market outcomes.

These results are consistent with our previous findings. Across all outcomes, none of the male coefficients are significantly different from zero. For females, on the other hand, we see a shift up starting in 1924-1925 or shortly thereafter, and coefficients generally remain higher than zero throughout the post-iodization period. In Figure A1A, the pattern of coefficients suggests that the spread and take-up of iodized salt was not immediate: the 1924-25 coefficient is very close to zero. Starting in 1926-1927, however, the positive effects begin to appear. Though the 1926-1927 interaction is not significantly different from zero, it is approximately the same magnitude as the two later coefficients, which are significant at the 10% and 5% level. The other outcomes show a similar pattern, although the upward shift in coefficients comes slightly earlier for weeks worked, and is most apparent starting in 1928-1929 for the income regression. These results are consistent with a rapid, though not instantaneous, take-up of iodized salt by the U.S. population, and validate our definitions of the During and After cohorts.

Figure A1: Year-by-Year Effects of Salt Iodization on Labor and Income Outcomes, By Gender

(A) Employment



(B) Labor Force Participation

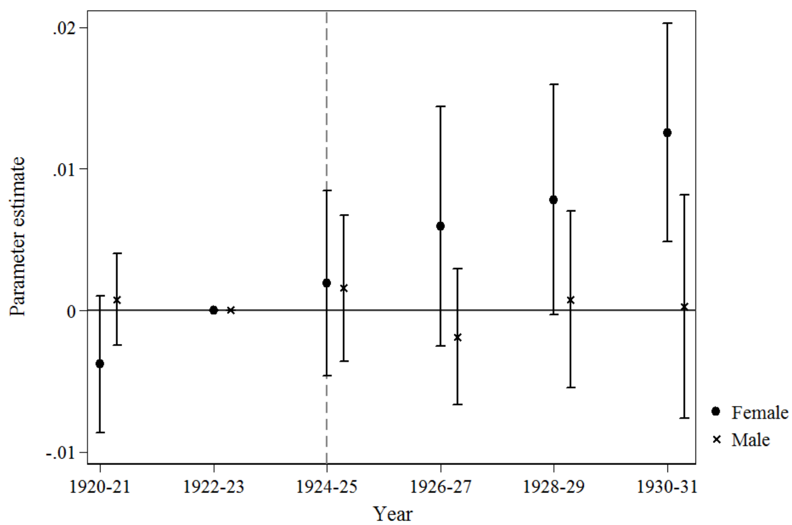
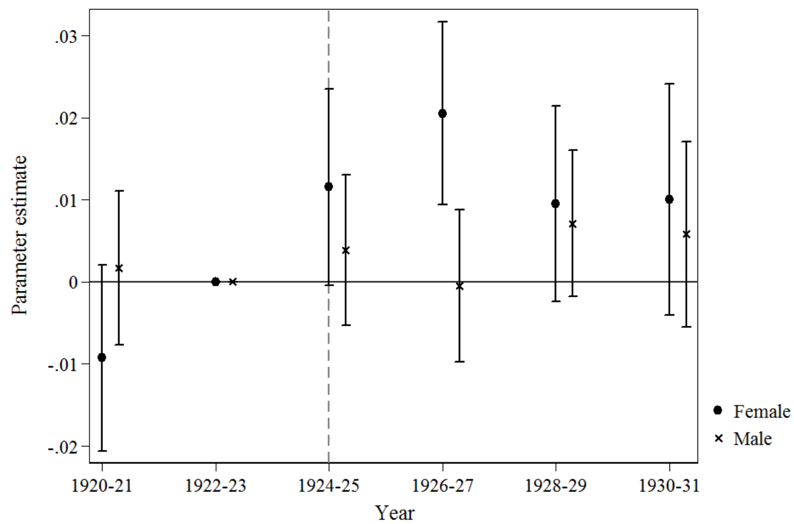
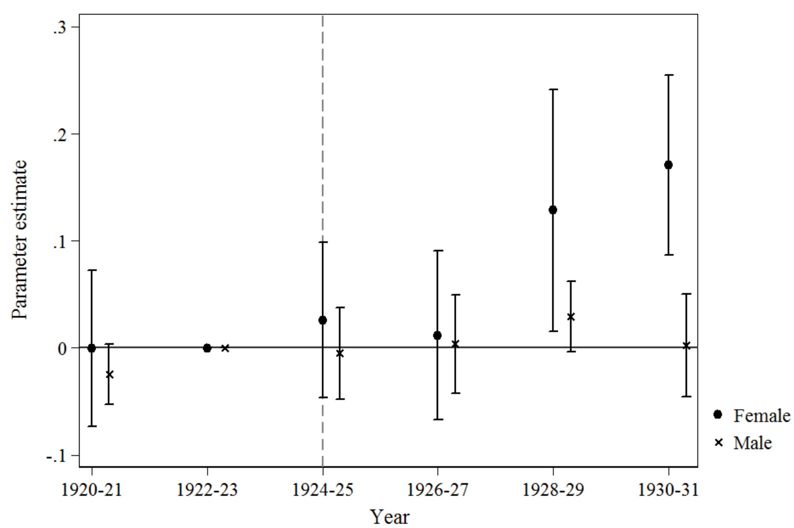


Figure A1: Year-by-Year Effects of Salt Iodization on Labor and Income Outcomes, By Gender (continued)

(C) At Least 40 Weeks Worked



(D) Income



Notes: Each point represents the coefficient estimate (and 90% confidence interval) for Goiter Rate interacted with the birth year indicator listed on the x-axis. These regressions use the 1950 to 1980 censuses, restricting to individuals born in 1920-1931. All regressions include state of birth fixed effects, year of birth x census year dummies, census division of birth x birth year dummies, gender, race, and During and After dummies interacted with average state latitude and 1920 state-level female and black proportions.

Table A6 reports the results of our regressions on marital and education outcomes, for men.

Table A6: Effects of Salt Iodization on Male Education and Marital Outcomes

	(1)	(2)	(3)
	Years of Schooling	1(Ever Married)	Age at First Marriage
After x Goiter Rate	0.0313	0.00288	-0.0405
	(0.0464)	(0.00235)	(0.0454)
During x Goiter Rate	0.0990**	0.00220	-0.0355
	(0.0396)	(0.00187)	(0.0594)
Observations	859574	859574	692623
Mean of Dep. Var.	11.45	0.937	24.16

Notes: Standard errors, clustered by state of birth, in parentheses (*** p<0.01, ** p<0.05, * p<0.1). Goiter Rate is the goiter rate in the individual's state of birth from Love and Davenport (1920), scaled by the difference between the 75th and 25th percentile of the goiter distribution (0.71). After is a dummy equal to 1 for those born 1928-1931. During is a dummy equal to 1 for those born 1924-1927. These regressions use the 1950 to 1980 censuses, restricting to men born in 1920-1931. All regressions include state of birth fixed effects, year of birth x census year dummies, census division of birth x birth year dummies, gender, race, and During and After dummies interacted with average state latitude and 1920 state-level female and black proportions.

B Data Appendix

B.1 Independent Indicator Variables

- *Before*=1 if individual was born in 1920-1924; *Before*=0 otherwise
- *During*=1 if individual was born in 1924-1927; *During*=0 otherwise
- *After*=1 if individual was born in 1928-1931; *After*=0 otherwise

B.2 Outcome Variables

B.2.1 Basic Outcomes

- *1(Participated in Labor Force)*=1 if the individual participated in the labor force (by either working or looking for work) in the last week;
  1(Participated in Labor Force)=0 if the individual did not participate in the labor force.
- *1(Employed)*=1 if the individual was employed in the last week;
  1(Employed)=0 if the individual did not work, irrespective of whether the individual looked for a job.
- *1(Worked at least 40 weeks)*=1 if the individual reported working at least 40 weeks in the last year.
  1(Worked at least 40 weeks)=0 if the individual worked fewer than 40 weeks in the last year. This variable is missing for individuals who did not work in the past year.
- *Total Income*: This is the inverse hyperbolic sine of the total annual income earned by the individual. All values are adjusted to 1999 prices according to Census-provided multipliers. Although this variable is top-coded differently across Census years, we applied the top-coding from the 1950 Census to all years (setting the maximum income to $70,000). The inverse hyperbolic sine transformation was made after all of the adjustments were made.
- *Years of Schooling*: Years of schooling completed by the individual.

B.3 Other Variables

- *female*=1 for females; *female*=0 for males
- *black*=1 for black individuals; *black*=0 for all other races

- *1920 female share*: The state-level proportion of the population that was female in the individual's state of birth, calculated from the 1920 Census.

- *1920 black share*: The state-level proportion of the population that was black in the individual's state of birth, calculated from the 1920 Census.

- *Latitude*: Average latitude for the individual's state of birth

- *Malaria*: Pre-iodization malaria rate in state of birth according to Bleakley (2010)

- *Hookworm*: Pre-iodization hookworm rate in state of birth according to Bleakley (2010)

- *Compulsory Schooling*: Number of years of schooling required by compulsory attendance laws in the individual's state of birth in the year they turned 14 (which is the minimum leaving age across all states and years), from Lleras-Muney (2002).

- *Mobilization Rate*: WWII mobilization rate for individual's state of residence, from Acemoglu et al. (2004).

- *1930 unemployment rate*: The state-level unemployment rate in the individual's state of birth, calculated from the 1930 census.

- *1920-1940 population growth*: The state-level change, between the 1920 and 1940 census, in the share of the U.S. population living in an individual's state of birth.

- *1920-1940 change in black share*: The state-level change, between the 1920 and 1940 census, in the black population share in an individual's state of birth.