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* to iodized salt with those of slightly older, unexposed cohorts, across states with high versus low iodine deficiency rates prior to salt fortification. Incomes for cohorts who benefited from iodized salt access went up by 3%, with an 8% increase during school-going ages. Employment rose by 1 percentage point, driven by a 2 point rise at school-going ages and focused on entry into low-wage jobs. Women experienced significantly larger increases than men–indeed, the overall effect is almost entirely due to changes in female income and employment.

Keywords: early life, cognitive ability, iodine, labor force participation, wage distribution
JEL Codes: I12, I15, I18, J24, N32

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1 Introduction

A long literature has studied the relationship between cognitive ability, schooling, and labor market outcomes. There is consensus in the literature that schooling choices, along with related investments, and subsequent labor outcomes all depend crucially on endowments of skills and abilities of many types (Heckman et al., 2006). However, how schooling and labor decisions might respond to interventions aimed at reducing inequalities in these endowments remains an open question. Some recent structural work has shown that returns to schooling and other investments vary both along the distribution of the ability endowment and across the life cycle (Cunha et al., 2010; Heckman et al., 2014). In the absence of such structure, estimating causal impacts of changes in ability endowments on labor market outcomes across the life cycle has proven quite difficult due to the scarcity of credibly exogenous variation in ability endowments, particularly in large datasets with sufficient heterogeneity and long-run outcome horizons. Following the suggestion made by Heckman (2006, 2007) that the early-life literature can help us to illuminate these relationships between dynamic skill production functions and life cycle labor outcomes, we exploit the first nation-wide micronutrient fortification program and its impacts on cognitive endowments to estimate the schooling and labor responses to improved cognition in the historical US.

We find an increase in labor force participation and income at the lower end of the income distribution. These findings are remarkably consistent with recent empirical evidence on the relationship between cognitive ability and labor outcomes. Heckman et al. (2014) find that increased cognition improves labor market outcomes apart from an indirect effect through changes in educational attainment. These findings are also consistent with the survey of recent empirical evidence and the model predictions regarding dynamic complementarities presented in Heckman and Mosso (2014). That is, at early stages of investment (i.e., primary school and junior high), we find that a rise in cognitive ability increases labor force participation and income, but has little effect on primary school and junior high completion.

We draw lessons from the historical experience of the United States, where natural access to iodine, an essential micronutrient, was scarce in many areas of the country until the mid-1920s. Iodine regulates thyroid hormone availability, which determines the density of fetal neural networks (Lamberg, 1991). Medical studies suggest that iodine deficiency affects cognitive function at all ages, but is particularly detrimental during gestation, when even mild deficiency can greatly hamper cogni-

tive 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 quotients (IQ), regardless of subsequent supplementation (Hetzel and Mano, 1989; Pharoah and Connolly, 1987; Zimmermann et al., 2005).[1]

We study the education, labor force, and income distribution 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 early 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 and Atland, 1952; Hamwi et al., 1952; Schiel and Wepfer, 1976). Feyrer et al. (2013) show that IQ may have risen substantially–up to 15 points–as a result. We ask: what happened to the economic outcomes of those whose *in utero* access to iodine improved? Did increased IQ affect labor market outcomes? Were labor supply and wages impacted significantly, and which parts of the income distribution did salt iodization most affect?

We use a simple difference in differences strategy 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 and 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 pooling the 1970 and 1980 censuses.

Individuals affected by salt iodization saw improved labor market outcomes. Specifically, we find that labor force participation rose by .4 percentage points and income increased by 3% for our full sample of individuals aged 19-60 in the 1950 to 1980 censuses. Labor market effects are particularly pronounced for women. These overall estimates mask much larger employment and income effects on individuals early in their careers (in the 1950 and 1960 censuses). We do not see these effects persist in later census years, when individuals affected by salt iodization instead appear to shift into self-

[1]It bears mention that studies from the medical literature are correlational: causal evidence on the effects of iodine exposure in humans is limited. The study by Feyrer et al. (2013) 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.

employment, often associated with higher cognitive ability (Levine and Rubinstein, 2013) as well as substantial non-pecuniary benefits (Hamilton, 2000; Hurst and Pugsley, 2011). We argue that these impacts are consistent with the biological mechanism of iodine's *in utero* impact. Given the threshold-type dose response to iodine, blanket access to iodized salt likely had a very targeted impact–at the bottom of the ability distribution. For normal cognitive functioning to be achieved, fetal iodine levels need to be above a "protective threshold" (Cao et al., 1994; Eltom et al., 1985; Furnee, 1997): those individuals who were previously below the protective threshold were pulled up above it, shifting the left tail of the ability distribution to the right.

Theoretical effects of increased cognition on schooling are ambiguous, as the direct wage returns to ability in low-skilled labor opportunities may counteract any impacts of ability on schooling returns at early ages. We find a small, negative effect on educational attainment (the magnitude is on the order of one week), concentrated at early stages of education (primary and junior high school). This negative effect is precisely estimated, meaning that we can rule out even moderate decreases in educational attainment. We find no effect on education at higher levels, consistent with the argument that access to iodine improved outcomes for those at the lower end of the ability distribution. This is consistent with (Bleakley, 2010) who finds mixed results of malaria eradication on schooling in four different countries.

Our results contribute new empirical evidence to the debate on the shape of the skill production function taking initial endowments and investments as arguments. A recent body of work–including Almond et al. (2009), Cunha et al. (2010), Aizer and Cunha (2012), and Bhalotra and Venkataramani (2012) among others, and reviewed in Almond and Mazumder (2013)–explores the degree to which initial disadvantages can be compensated for with parental investments, and whether the ability to compensate is higher or lower at early verses late stages of development.

We also add to the growing literature on the long-term effects of early-life conditions.[2] Much of this "fetal origins" work has focused on demonstrating the impacts of traumatic experiences (disease, natural disasters, environmental factors, etc.) in early life. Few studies have estimated the gains to exposure to purposeful and beneficial 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 small set of studies–including Hoynes et al. (2012), Bleakley (2007), Bleakley (2010), Field et al. (2009), Almond et al. (2010),

[2]See Heckman (2006), Almond and Currie (2011), and Currie and Vogl (2012) for syntheses of this literature.

Politi (2011b), Bhalotra and Venkataramani (2012), and Feyrer et al. (2013)–have recently made strides in this direction.[3] 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.

The fact that our results are strongest for women is consistent with evidence from recent studies on the effects of other early life interventions (Bleakley, 2007; Field et al., 2009; Hoynes et al., 2012; Maccini and Yang, 2009). Moreover, this pattern relates to important previous work on the drivers of the marked rise in labor force participation and educational attainment of women over the 20th century. Goldin and Olivetti (2013) and Goldin (1991) estimate that WWII led to a roughly 20 percent rise in female participation for higher-educated women in cohorts born between 1915 and 1924. Goldin and Katz (2002) and Bailey (2006) 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 that salt iodization led to a rise in female labor force participation of roughly 2 percent among cohorts joining the labor force after the war, but largely completing their fertility prior to improved access to contraception.

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. Inadequate access to essential micronutrients such as iron, vitamin A, iodine, and zinc in low-income countries has staggering costs in terms of mortality, poor health, and lost productivity (Black et al., 2013). The short-term health benefits of improving micronutrient availability, especially for young children, are clear (Bhutta et al., 2013), but little is known about impacts in the long run. Moreover, few studies have examined the impacts of large-scale supplementation campaigns.[4] Our study focuses on the problem of iodine deficiency. Nearly 2 billion people worldwide–a third of the world's population–do not have adequate access to iodine (Andersson et al., 2010; de Benoist et al., 2004). Recent estimates from the economics literature suggest that the incidence of iodine deficiency, and thus the returns to reducing IDD, may be very large (Feyrer et al., 2013; Field et al., 2009; Politi, 2011b). Policymakers in IDD-endemic countries,

[3]Our results stand in contrast to Politi (2011b)'s findings on the impacts of salt iodization in Switzerland. She finds that high school and college completion both rose as a result of iodization. This may be because the sectoral composition of the economy made returns to higher education very different in Switzerland.

[4]Notable recent exceptions are Feyrer et al. (2013), Politi (2011b), and Politi (2011a), which we will discuss in detail. Much of the available evidence is from the INCAP longitudinal study (Martorell, 1995), which followed Guatemalan children from 4 small villages over 20 years, some of whom were exposed to a nutrient intervention *in utero* and in early life, and others who were given a placebo.

as well as the WHO, UNICEF, and other international organizations, have made increasing access to iodine a high priority (WHO, 1992). 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 (Center, 2008).

It is important, then, as many low-income countries make decisions about investing in salt fortification and distribution infrastructure, to quantify in rigorous fashion the economic benefits of salt iodization. Clearly, there are many differences–related to infrastructure, centralization of distribution, competing disease risks, labor markets, etc.–between the US in the early- and mid-twentieth century and the low-income countries still suffering from high rates of IDD today. But drawing from the historical experience in the US offers some insight into the promise of salt iodization, in terms of the rate and completeness of adoption and the long-term economic returns that could be achieved.

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 describes our empirical strategy. Section 5 describes 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.[5] 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 and transported throughout the body to control metabolism (the conversion of oxygen and calories to energy). The highest iodine contents for human consumption are found in some milks, leafy vegetables, and sea foods. The optimal iodine intake as recommended by the WHO is very small: a daily dose of 90 μg for infants of 0-59 months, 120 μg for ages 6 to 12, 150 μg for older ages, and 200 μg for pregnant and lactating women (Clar et al., 2002). (Half a teaspoon of iodized salt contains about 150 μg of iodine). Nevertheless, iodine deficiency can be a risk for many people due to the minute iodine content in most foods, and is most likely in areas far from the sea, especially mountainous areas due to erosion (Hetzel, 1989). When iodine intake is insufficient, the thyroid gland gets enlarged by working

[5] http://www.endocrineweb.com/thyfunction.html

extra hard to produce the needed thyroid hormones.

At any stage from the fetal age to adulthood, insufficient iodine intake can cause a number of functional and developmental abnormalities, often referred to as iodine deficiency disorders (IDD). The main IDDs are goiter, hypothyroidism (causing fatigue, lethargy, slow speech and thought), impaired mental function, retarded physical development, and increased susceptibility of the thyroid gland to nuclear radiation (WHO, 2004).[6] Although the most detrimental IDD is cretinism due to severe iodine deficiency, less extreme in utero and postnatal deficiency can also be highly damaging and result in a 5%-50% loss of individual productivity depending on severity (Hetzel and Pandav, 1996).

Correlational evidence of the impact of iodine deficiency on human capital among school-age children is abundant. Huda et al. (1999) find that in Bangladesh hypothyroid children performed worse than those with normal thyroid gland function on reading, spelling and cognition, controlling for health and socioeconomics. Even in a developed-country area with very mild iodine deficiency (Jaen, Spain), Santiago-Fernandez et al. (2004) report the risk of having an IQ below 70 to be greater in children with urinary iodine levels less than 100 μg/liter.

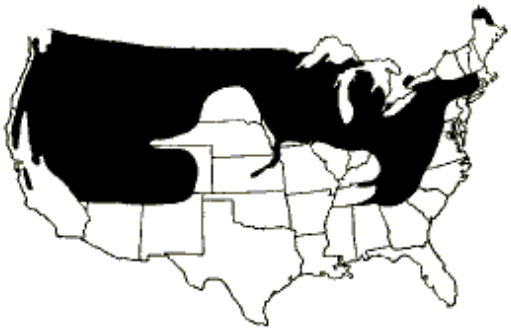
2.2 The Geography of Iodine Deficiency in the US

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 and only nationwide goiter survey in the US. A "goiter belt" can be seen in the northern parts. The figure also shows a very similar geographic pattern in goiter incidence among WWI recruits and in the iodine content of drinking water as reported in 1924 by the then prominent scientist Jesse Francis McClendon (map on the right). The similarity between these two patterns suggests that the WWI draft statistics offer a good representation of the geographic pattern of iodine deficiency in the general population. In our estimations, we do not use McClendon's water iodine content data, as the author presents numerical information for only 27 states, many of which use data from only one location.

In a 1929 publication in the Public Health Reports, Robert Olesen, a surgeon at the U.S. Public Health Service, reported data on goiter rates across the country which he started collecting in 1924. He consulted independent thyroid surveys and directly communicated with state, county and city health officers across the country to compare the geographic distribution of goiter in the general public to the

[6] 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 aspiratory difficulty.

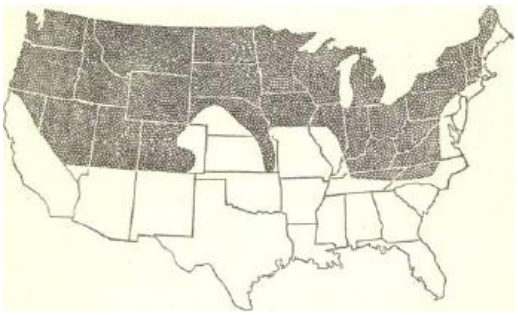
Figure 1: Simple Goiter Incidence Among US Drafted Men in World War I and Iodine Content of Drinking Water in the US



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)

findings from the WWI draft examinations. Olesen (1929) concludes that his evidence from elementary school to college aged samples confirms the geographic variation in goiter incidence among WWI recruits in those areas where he was able to collect data. Summarized in column 1 of Table A1, the WWI 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 region-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

It was not until 1895 that iodine was first discovered in the thyroid gland by a German chemist Eugen Baumann (Baumann, 1896). Since then experiments were conducted to study the impact of changes in iodine content and the enlargement of the incidence of goiter in different kinds of animals, including dogs, cattle, hogs, and fish (Marine and Feiss, 1915; Marine and Lenhart, 1909; Smith, 1917). However, it was only in 1914-1915 that goiter in humans was reported in an organized manner in the US for the first time by Hall (1914) and Olesen (1915), using examination data from 3,339 University of Washington students and from 606 women and 193 men in Chicago, respectively. The experiment of scientist David Marine and colleagues in Ohio in 1917-1919, providing iodated syrup to school girls of grades 5

to 12, offered the first known evidence that iodine supplementation could control and prevent goiter in humans (Marine and Kimball, 1917). Two grams of iodated syrup were given twice a year to 2,190 of 4,495 school girls in Akron, Ohio. Only five treated girls developed thyroid enlargement whereas 495 untreated girls did. Among the girls with initial thyroid enlargements, 70% of the treated showed a gland size decrease while only 15% of those not treated showed such a decrease (Marine and Kimball, 1921).

Coincidental with findings from the Ohio experiment, a few other factors put focus on goiter in humans as a health problem in America during the early 1920s (Annegers and Mickelsen, 1973). These included: (a) the 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). The evidence by Marine and colleagues inspired Switzerland to set up prophylactic programs, one of which used salt as an iodization vehicle.

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.[7] 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 prohibiting non-iodine fortified salt (Markel, 1987), however 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. He also contacted the Morton Salt Company in Chicago, who initially resisted because costs would double if they had to separate one version of salt for Michigan retailers. 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 popular and Morton Salt Company began nationwide

[7] "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)

distribution two months later. With educational efforts of the Michigan State Medical Society, giving lectures on the medical benefits of iodized salt, and zealous advertisements by salt producers,[8] 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 and 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. Figure 2 shows U.S. goiter survey results 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

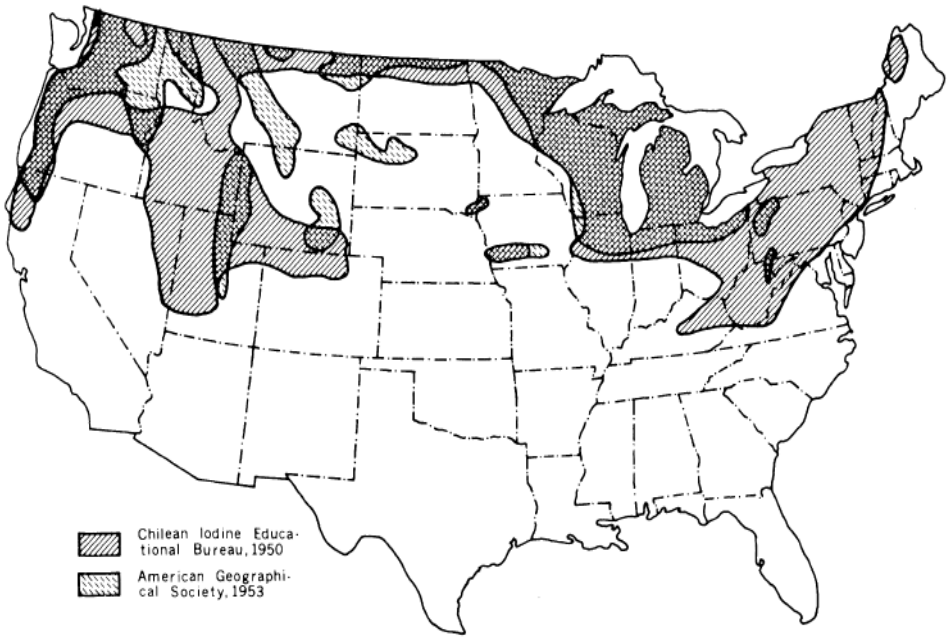
Marine's 1917-19 experiment was the first to inform the US public that iodine supplementation could prevent and treat goiter; hence there is little reason to suspect a *direct* role of iodine in residential selection or selection into iodine-rich diets. Supporting this claim, Figure 1 shows that goiter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

However, one might still suspect that high goiter incidence areas prior to iodization were also more likely to have high incidence of other nutrient deficiencies or other health issues such as malaria or hookworm. Similarly, we might worry that concurrent with the roll out of iodized salt, there may have been other important changes in the U.S. diet or in other health conditions. 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, due to high malnutrition rates and fears of potential U.S. involvement in war.

Figure 3 shows the change in the per capita riboflavin, iron, niacin, and thiamin contents of Ameri-

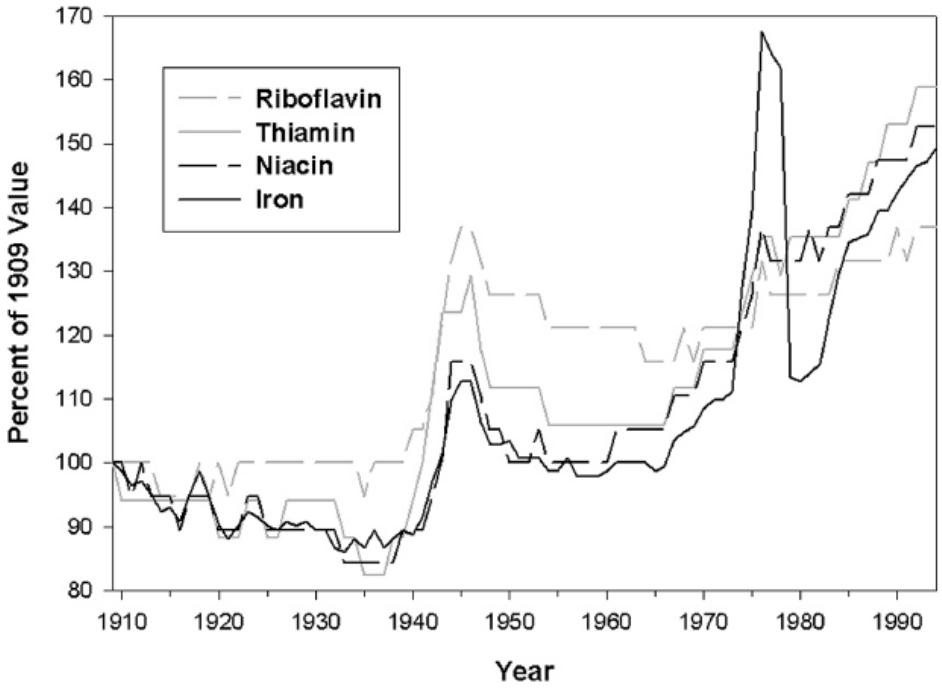
[8] Advertisements would often contain phrases such as "Remember, too, that Morton's Iodized Salt protects children against simple goiter - that often unnoticed nutritional disease which is frequently accompanied by underdevelopment, irritability and backwardsness at school." (Women's Home Companion,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

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



Source: Schiel and Wepfer (1976)

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)

can food between 1909 and 1994, which does not coincide with the timing of salt iodization. In order to address concerns about the contemporaneous eradication of infectious diseases, we check the robustness of our main results to controlling for baseline geographic variation in the prevalence of malaria and tuberculosis as well as the interactions of these rates with a post-iodization dummy. The robustness of our results alleviates concerns about the geographic pattern of goiter incidence, and hence of expected benefits from iodized salt, coinciding with the geographic pattern of other health-related improvements.

3 Data

3.1 Goiter Data

Our information on the geographic distribution of iodine deficiency prior to salt iodization 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. Love and Davenport (1920) documents prevalence rates in this sample for over 200 medical conditions, including goiter. In this paper, we use the state-level prevalence rates, although rates for smaller regions (collections of counties known as sections) were recorded as well.[9] We use goiter rates as a proxy for state-level iodine deficiency rates prior to salt iodization. Column 1 of Table A1 reports for each state the goiter rate recorded in Love and Davenport (1920). The median goiter rate is .214% and the maximum is 2.686% .

We also check for robustness to another source of goiter data, a list of goiter rates among children complied by Olesen (1929). Starting in 1924, these rates were calculated by experienced health workers from samples of school children in a varying number of localities in 43 states. 6 out of these 43 states did not report a numerical goiter rate (only qualitative descriptions, like "very little goiter") and were therefore excluded. Column 2 of Table A1 reports the goiter rates from this dataset for the remaining 37 states. Appendix section B.4 contains more details about how state-level averages were calculated for this dataset. The median goiter rate in this sample is 9.1%. Due to the greater noticeability of goiter

[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.

among children compared to adults and the more stringent requirement for goiter to be recorded in the military records,[10] the Olesen (1929) rates are much higher than the rates from Love and Davenport (1920). The correlation between the two measures of goiter is 0.45.

3.2 Census Data

We also use data from the United States Decennial Census, 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 education, labor, and income outcomes for this cohort in the 1950 to 1980 censuses, when they are 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 from 1924 to 1927 are classified as born "during iodization," and those born from 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 interested in individuals' participation in the labor force as well as the types of occupations they hold. To represent employment, we use two variables: a dummy for labor force participation (which includes job-seekers as participants) and an unconditional dummy for employment (which is set to zero for job-seekers). We also look at whether individuals are self-employed. Another outcome of interest is the inverse hyperbolic sine of total income, which includes income from all sources, including wages and self-employment income. Finally, we create dummy variables to identify the income quintile to which each individual belongs. We first calculate log income quintiles from the 1950 census (in 1999 dollars). We then define, for each individual, dummies for inclusion in each income quintile. We apply the same income cutoffs for inclusion in each quintile to later census observations to map how each cohort's income distribution shifted. The education outcomes we study are years of completed schooling and dummies for primary, junior high, high school, and college completion.

[10] Goiter was recorded in the military recruit data if it was large enough to prevent the buttoning of a uniform collar.

Table 1: Summary Statistics for Individuals Aged 25-55, 1940 Census

	Mean	Standard Deviation	Number of Observations
1(Participated in Labor Force)	0.62	0.486	678429
1(Employed)	0.56	0.496	678429
1(Self-Employed)	0.18	0.385	412717
Years of Schooling	9.17	3.411	678429
Wage Income	11748.31	10252.5	333967
1(Female)	0.50	0.500	678429
1(Black)	0.11	0.308	678429

Notes: Wage income in 1999 dollars.

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

3.3 Census Division Controls

There are clear regional patterns in the distribution of goiter. This necessitates the inclusion of Census division by birth year dummies, which we use in all of our specifications. We control for region of birth using the nine Census Bureau divisions, listed in Table A1. The inclusion of these interaction terms means we are identifying off of within-division variation, essentially comparing states across the goiter distribution within each of the nine divisions in terms of their deviations from the division's non-linear trend across birth cohorts in the outcome variable.

3.3.1 Summary Statistics

Table 1 reports summary statistics for the entire population aged 19-60 in the 1940 Census. As 1940 was the last Census year before the during and after cohorts entered our sample as working adults over 18 years old, this gives us a snapshot of pre-treatment labor outcomes, educational attainment,

and demographic composition.[11] Column 1 displays statistics for the whole sample: about 62% of the sample participated in the labor force, and the majority of these individuals were employed. On average, individuals attended school until the ninth grade.

3.4 Other Diseases

In certain robustness checks, we control for the pre-iodization rates of two other diseases: malaria and tuberculosis. We take tuberculosis rates from the Love and Davenport (1920) data, which also recorded rates of various other "defects" found in recruits. For malaria, we use the malaria mortality rates from the 1890 Census, used in Bleakley (2010).

3.5 Compulsory Schooling and State Mobilization Rates

In another robustness test, we add years of compulsory schooling as a control variable. 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.

We also include WWII state mobilization rates, obtained from Acemoglu et al. (2004), as a control. Due to timing of the war, if WWII mobilization had any impact on these individuals, it likely 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

In this section, we describe the empirical strategy we use to identify the effects of salt iodization on economic outcomes. 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

[11] Total income is a variable we use in our analysis but is not available in the 1940 Census. Instead of total income, we report wage income, which is available in the 1940 census but does not include income from sources other than wage work.

nationwide, however, 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 in states with different levels of pre-iodization iodine deficiency rates. Feyrer et al. (2013) use a 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 and 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. (2013), 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 this 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 practice, the magnitudes of estimates for impacts in these two cohorts are very similar, suggesting that iodized salt did indeed proliferate very quickly.

We interpret differences in trends in economic outcomes across individuals born in states with varying levels of goiter as causally related to salt iodization. Although there does exist a "protective threshold" that fetal iodine must reach in order to ensure normal cognitive functioning, we do not know what this threshold is and how to map it to goiter prevalence rates. We therefore take an agnostic approach and use continuous goiter rates to capture differential cohort trends that vary along the ordering of states by risk of iodine deficiency.

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. In our baseline specification, we use the continuous goiter rate (but in robustness checks, we split the sample at the 75th percentile, creating a high goiter v. low goiter designation as in Feyrer et al. (2013)). We estimate the following specification, for individual i born in year t in state s (census division d), for outcome o 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:

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

Here, β_1 and β_2 are the main coefficients of interest, measuring the difference in trends in outcome o across individuals exposed to different levels of iodine deficiency over time. The specification includes state of birth (μ_s) and year of birth fixed effects (δ_t, which are interacted with census years as well as divisions), which absorb the main effects of G_s, D_t, and A_t. The census division of birth by birth year interactions $(\zeta_d \text{ x } \delta_t)$ are crucial because they control for any division-specific trends over time that may coincide with the national goiter distribution. In particular, division-by-birth-year fixed effects should alleviate concerns about differential trends for Northern and Southern states because we are comparing outcome variable trends (by birth cohorts) across high and low goiter states of birth in their deviations from each Census division's mean non-linear trend. $(\lambda_c \text{ x } \delta_t)$ are census year 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 residence, interacted with the during and after dummies. Standard errors are clustered at the state of residence level to allow for arbitrary correlation of the errors for individuals residing in the same state.

In order to trace out the effects of salt iodization on labor market outcomes as our cohorts age, we also run this regression 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).

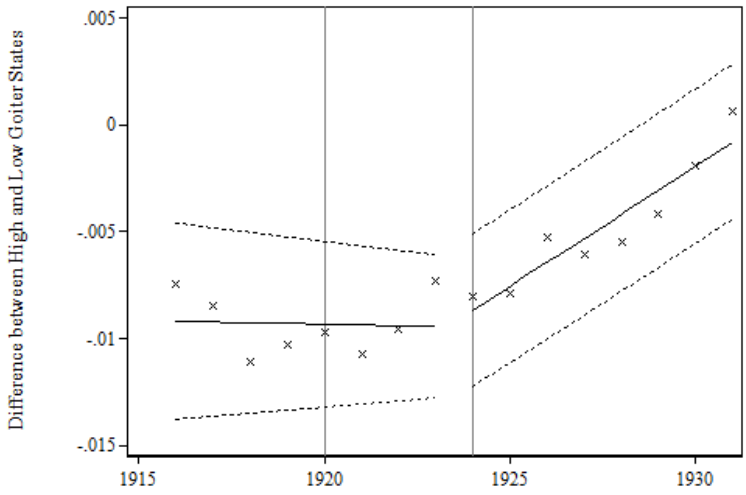
We test the robustness of our results to the inclusion of contemporaneous disease eradication programs (namely related to tuberculosis and malaria) as well as compulsory schooling laws and WWII mobilization rates at the state of residence. We also show robustness to the use of a discrete cutoff

instead of continuous goiter rates and to an alternative source of data, the goiter rates among school children collected by Olesen (1929). Finally, to address issues of measurement error in our treatment variable we instrument for goiter rates in the military recruit data with the goiter rate from Olesen (1929).

5 Results

5.1 Labor Supply and Income

Figure 4: Trends in the High Goiter-Low Goiter Labor Force Participation Differential



Notes: Solid lines depict local linear regressions of the difference between labor force participation residuals across high and low goiter states, calculated separately for the years 1916-1923 and 1924-1931. Dotted lines represent 90% confidence interval for these differentials. To illustrate the graphical analog of our regression specification, we calculate labor force participation and goiter rate residuals after regressing these variables on birth year by census division fixed effects, birth year by census year fixed effects, gender, race, and 1920 state-level female and black proportions interacted with during and after dummies. The sample is split into high and low goiter using the 75th percentile of the goiter rate residuals.

Figure 4 plots local linear regressions of the difference in labor force participation residuals among individuals born in high and low-goiter states, by birth year, from 1916 to 1931. For this descriptive analysis, we classify states into high and low goiter using the 75th percentile (the same cutoff as Feyrer et al. (2013)) of the goiter rate residual distribution, but do not rely on this arbitrary cutoff for our main regression analysis.[12] 90% confidence intervals are denoted by the dotted lines. The first vertical

[12]Residuals for both schooling and goiter rate are calculated after regressing these variables on birth year by census division fixed effects, birth year by census year fixed effects, gender, race, and 1920 state-level female and black proportions interacted with during and after dummies. Birth state fixed effects are not included because goiter rate varies at this level.

line indicates the beginning of our "before" cohort, and the second vertical line marks the beginning of our iodine-exposed ("during" and "after") cohorts. We include the four birth years prior to those included in our sample in order to show that high and low goiter states exhibited similar pre-trends, an important check for the validity of the assumptions of our difference-in-differences strategy.

For cohorts born during the pre-iodization period (1916 to 1923), that the gap between high and low goiter states in labor force participation was relatively flat. In the year of the introduction of iodized salt, however, we see a shift upward, followed by a gradual increase across the 1924 to 1931 birth cohorts, implying that among these younger cohorts, individuals born in high goiter states saw relatively larger increases in participation rates than those born in low goiter states, compared to the older cohorts. The upward slope likely reflects the fact that the spread of iodized salt across the country, though rapid, did not occur in just one year.

Though suggestive of a causal relationship between salt iodization and labor force participation, this analysis does not allow us to control for state of birth fixed effects in the calculation of residuals (because the goiter rate variable is defined at the state of birth level). Moreover, these figures ignore much of the variation in goiter rates by splitting the sample into only two groups. We address both of these issues using regression analysis, estimating the specifications described in section 4.

In all of the regressions that follow, 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. Our specification includes state of birth fixed effects, year of birth by census year interactions, census division of birth by birth year interactions, a female dummy, a black dummy, and 1920 state-level female and black proportions interacted with the after and during dummies. Table 6 displays results on education outcomes. In all of the regressions that involve a continuous goiter rate, we multiply each relevant coefficient by the inter-quartile range of the goiter distribution (0.713) 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).

Table 2 summarizes the regression results for our labor outcomes of interest. The effects of salt iodization on labor force participation (column 1) and the probability of being employed (column 2) are both positive and significant, with effect sizes ranging from 0.37 to 0.62 percentage points. In addition, salt iodization appears to have shifted workers into self-employment, a result that is consistent with recent evidence on the positive link between cognitive ability and entrepreneurship (Levine and Rubinstein, 2013). This table also documents an approximately 3% increase in total income.

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

	(1)	(2)	(3)	(4)
	1(Participated in the Labor Force)	1(Employed)	1(Self-Employed)	Total Income
After x Goiter Rate	0.00370*	0.00624***	0.00335*	0.0301*
	(0.00204)	(0.00182)	(0.00171)	(0.0173)
During x Goiter Rate	0.00122	0.00254	0.00508***	0.00762
	(0.00189)	(0.00198)	(0.00134)	(0.01000)
Observations	2289711	2289711	1776383	2042232
Mean of Dependent Variable	0.679	0.652	0.107	8.575

Notes: Standard errors, clustered by state of residence, 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 1920 state-level female and black proportions interacted with During and After dummies.

Table 3: Effects of Salt Iodization on Labor and Income Outcomes over Career Path

	(1)	(2)	(3)	(4)
	1(Participated in the Labor Force)	1(Employed)	1(Self-Employed)	Total Income
Panel A: 1950-1960 Censuses				
After x Goiter Rate	0.0113***	0.0152***	-0.000230	0.0768**
	(0.00296)	(0.00273)	(0.00408)	(0.0338)
During x Goiter Rate	0.00465	0.00693*	0.00153	0.0134
	(0.00328)	(0.00359)	(0.00305)	(0.0298)
Observations	593236	593236	423874	350976
Mean of Dependent Variable	0.632	0.602	0.0814	7.306
Panel B: 1970-1980 Censuses				
After x Goiter Rate	0.000762	0.00305	0.00449***	0.0221
	(0.00264)	(0.00240)	(0.00152)	(0.0204)
During x Goiter Rate	-0.000175	0.000941	0.00622***	0.00699
	(0.00247)	(0.00240)	(0.00142)	(0.0120)
Observations	1696475	1696475	1352509	1691256
Mean of Dependent Variable	0.695	0.669	0.115	8.838

Notes: Standard errors, clustered by state of residence, 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 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 1920 state-level female and black proportions interacted with During and After dummies.

5.1.1 Effects Over Career Path

We next ask whether the effects of this cognitive shock affected labor market outcomes differentially over the course of these individuals' careers. In particular, we are interested in comparing effects in the first and second half of their working lives. 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 pooling the 1970 and 1980 censuses (during which they were 39 to 60 years old). Table 3 reports these regressions in Panels A and B, respectively, and reveals some interesting patterns. Comparing the results of the two panels in columns 1, 2 and 4, it is clear that the positive labor force and income effects found in the full sample (Table 2) are completely driven by the large impact salt iodization had on individuals early in their careers. The effects on labor force participation, employment, and income are positive and significant (and larger than the full-sample estimates in Table 2) in Panel A, and statistically indistinguishable from zero in Panel B. In column 3, we see that salt iodization significantly increased self-employment for older workers only. Given that the non-pecuniary benefits of self-employment, which include flexible work hours and being one's own boss, are substantial (Hamilton, 2000; Hurst and Pugsley, 2011), this result suggests that salt iodization may have increased utility without increasing income during this period.[13] The concentration of the self-employment effect among older workers suggests that the cognitive ability improvements that led to higher income early in life eventually allowed individuals to transition out of salaried employment into more flexible self-employment.

5.1.2 Gender Heterogeneity

In the next two tables, we document some interesting gender heterogeneity in the patterns just described. Table 4 repeats the analysis in Panel A of Table 3 for men and women separately. Table 5 does the same for the later two census waves (Panel B of Table 3). In Table 4, it is clear that the positive effects of salt iodization on income and employment early in an individual's career are larger among women. Although male employment does significantly increase as a result of salt iodization, this effect is significantly smaller in magnitude than the effect for females. Moreover, the significant increase in income in the full sample appears to be completely driven by women, for whom salt iodization resulted in a sizable 12% increase in total income. This is consistent with the hypothesis that female fetuses are more sensitive to maternal thyroid deficiency than male fetuses, for which supporting evidence exists

[13] It should be noted that total lifetime income, due to the positive effects earlier on, is higher as a result of salt iodization.

in both the economic and biological literature (Field et al., 2009; **?**).

In Table 5, although both men and women demonstrate a shift into self-employment, this effect (in particular, the after-by-goiter coefficient) is significantly larger among men. A comparison of mean self-employment rates for men and women (15.8% versus 5.8%) reveals that men may simply have more self-employment opportunities, which could be contributing to this result.

5.1.3 Distributional Effects

All of the preceding analysis deals with average effects, but the biological pathway through which iodine affects cognitive ability suggests that distributional impacts may be important as well. Because the benefits of iodine are likely concentrated among those on the lower tail of the ability distribution (in other words, those falling below the "protective threshold"), we would expect the effects of iodine on the distribution of income to reflect this. To investigate this in more detail, we run five regressions using the income quintile dummies as dependent variables. Each dummy variable indicates an individual's inclusion in each of the quintiles of the 1950 Census distribution, as described in section 3.2.1. The coefficients from these five regressions are graphed in Figure 5, along with their 90% confidence intervals. The left panel depicts the scaled during-by-goiter coefficients, and the right panel the after-by-goiter coefficients. In both figures, there is a similar pattern of results: positive coefficients for the four quintiles, but negative coefficients for the 5th quintile. Appendix Table A3 reports the regressions corresponding to this figure. The after-by-goiter coefficients for the first and third quintiles regression are positive and significant at the 5% level, while the coefficient on the 5th quintile is negative and significant at the 10% level. These distributional income results emphasize that the positive labor force impact of salt iodization was concentrated at the left tail of the skill distribution and allowed people to enter the labor force and take up low-paying jobs.[14] Given that improvements in fetal iodine levels should affect those who would have had low cognitive functioning otherwise, not those who would have already achieved high cognitive functioning, this evidence is consistent with the biological mechanisms underlying these labor market effects.

Table 4: Effects of Salt Iodization on Labor and Income Outcomes in Early Censuses, by Gender

	(1)	(2)	(3)	(4)
	1(Participated in the Labor Force)	1(Employed)	1(Self-Employed)	Total Income
Panel A: Female				
After x Goiter Rate	0.0189***	0.0209***	-0.00280	0.150**
	(0.00537)	(0.00485)	(0.00323)	(0.0604)
During x Goiter Rate	0.00680	0.00836*	-0.00203	0.0429
	(0.00507)	(0.00495)	(0.00277)	(0.0483)
Observations	306087	306087	156689	180375
Mean of Dependent Variable	0.365	0.347	0.0245	4.511
Panel B: Male				
After x Goiter Rate	0.00449	0.0104***	0.00236	-0.0131
	(0.00309)	(0.00273)	(0.00602)	(0.0222)
During x Goiter Rate	0.00168	0.00486	0.00424	-0.0248
	(0.00278)	(0.00308)	(0.00447)	(0.0230)
Observations	287149	287149	267185	170601
Mean of Dependent Variable	0.917	0.875	0.115	10.26
Panel C: Female-Male Difference				
After x Goiter Rate	0.0144**	0.0105*	-0.00516	0.163**
	(0.00657)	(0.00577)	(0.00781)	(0.0654)
During x Goiter Rate	0.00512	0.00350	-0.00627	0.0677
	(0.00499)	(0.00404)	(0.00561)	(0.0472)

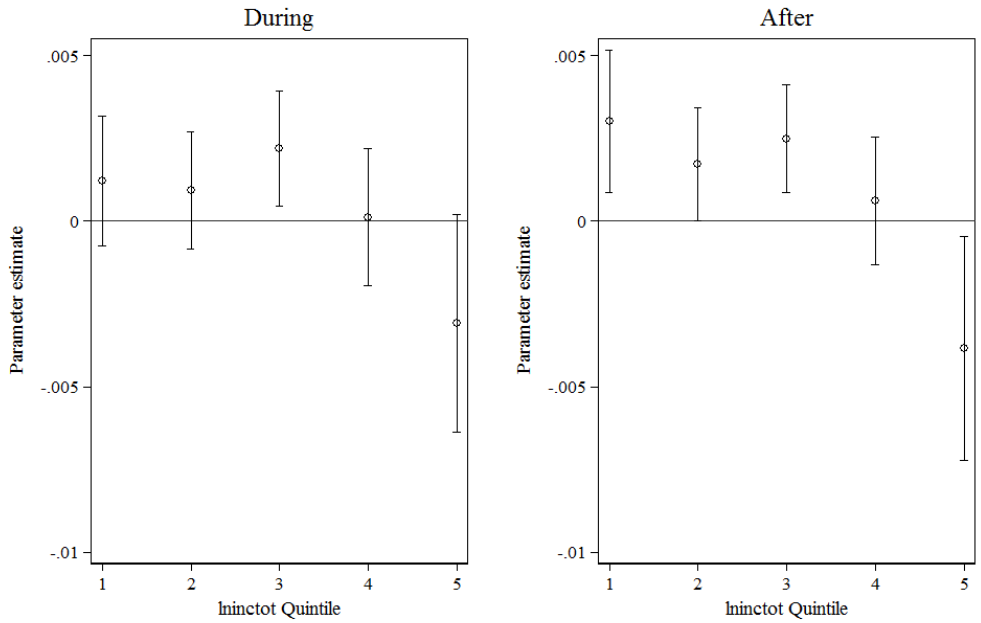
Notes: Standard errors, clustered by state of residence, in parentheses (*** p<0.01, ** p<0.05, * p<0.1). Goiter Rate is the goiter rate in the individual's state of birth from Love and Davenport (1920), scaled by the difference between the 75th and 25th percentile of the goiter distribution (0.71). 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 1960 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, race, and 1920 state-level female and black proportions interacted with During and After dummies.

Table 5: Effects of Salt Iodization on Labor and Income Outcomes in Late Censuses, by Gender

	(1)	(2)	(3)	(4)
	1(Participated in the Labor Force)	1(Employed)	1(Self-Employed)	Total Income
Panel A: Female				
After x Goiter Rate	0.00104	0.00306	0.000380	0.0363
	(0.00318)	(0.00294)	(0.00119)	(0.0367)
During x Goiter Rate	-0.000235	-0.000487	0.00452***	0.00636
	(0.00310)	(0.00300)	(0.00135)	(0.0242)
Observations	882401	882401	585458	880404
Mean of Dependent Variable	0.529	0.507	0.0585	6.925
Panel B: Male				
After x Goiter Rate	-0.0000161	0.00261	0.00760***	0.00141
	(0.00267)	(0.00256)	(0.00235)	(0.00961)
During x Goiter Rate	-0.000676	0.00195	0.00752***	0.00123
	(0.00286)	(0.00294)	(0.00216)	(0.0105)
Observations	814074	814074	767051	810852
Mean of Dependent Variable	0.875	0.845	0.158	10.92
Panel C: Female-Male Difference				
After x Goiter Rate	0.00106	0.000450	-0.00722***	0.0349
	(0.00264)	(0.00279)	(0.00251)	(0.0360)
During x Goiter Rate	0.000441	-0.00244	-0.00300	0.00513
	(0.00342)	(0.00356)	(0.00248)	(0.0295)

Notes: Standard errors, clustered by state of residence, 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 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, race, and 1920 state-level female and black proportions interacted with During and After dummies.

Figure 5: Income Quintile Regression Coefficients



Notes: Scaled during-by-goiter coefficients for each quintile are plotted in the left graph, while scaled after-by-goiter coefficients for each quintile are plotted in the graph on the right. 90% confidence intervals are also shown.

Table 6: Effects of Salt Iodization on Education

	(1)	(2)	(3)	(4)	(5)
	Years of Schooling	1(Completed Primary)	1(Completed Junior High)	1(Completed High School)	1(Completed College)
After x Goiter Rate	-0.0428*	-0.00508***	-0.00627***	-0.00164	-0.00199
	(0.0230)	(0.00122)	(0.00189)	(0.00431)	(0.00261)
During x Goiter Rate	-0.0109	-0.00292***	-0.00393***	-0.00156	0.000823
	(0.0193)	(0.00101)	(0.00142)	(0.00351)	(0.00185)
Observations	2047767	2047767	2047767	2047767	2047767
Mean of Dependent Variable	11.36	0.957	0.903	0.614	0.124

Notes: Standard errors, clustered by state of residence, 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 1920 state-level female and black proportions interacted with During and After dummies.

5.2 Education

We now turn to the effect of salt iodization on education, for which the theoretical predictions are more ambiguous. In Appendix C, we show 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.[15] Indeed, the first column of Table 6 shows that the effect of salt iodization on total years of completed schooling is very small in magnitude: a reduction of 0.04 years. Although this coefficient is statistically significant, it is not economically significant and translates to only 7 days of schooling.[16] Columns 2 to 5 show that this result is driven by early years of schooling: salt iodization significantly reduced the probability of primary and junior high completion (by less than 1% of the mean) but had no impact on high school or college completion. With our labor market results, these findings suggest that improved cognitive ability allowed individuals to work and earn more without obtaining more schooling. In Appendix Table A2, we show that the small negative schooling result is largely driven those living in blue-collar states, where individuals were a priori more likely to go into jobs with lower returns to schooling.

5.3 Robustness

We run additional regressions to check the robustness of our main results to additional controls and alternate explanations for the patterns observed. We might be concerned that other contemporaneous health improvements, such as the eradication of diseases or development of new treatments, which occurred roughly contemporaneously to the roll out of iodized salt, might be driving the results. In particular, malaria eradication programs, concentrated in the South, took place in the 1920's (Bleakley, 2010). The 1940's, on the other hand, saw strides in the treatment and prevention of tuberculosis, which could have had contemporaneous effects on the labor market outcomes of our sample cohorts.[17] The correlation between early 1900's goiter rates and prevalence of tuberculosis and malaria are weak and negative (-0.3 and -0.36, respectively) and thus unlikely to be driving our results. We validate this,

[14] It should be noted that these quintile dummies are created using the 1950 income distribution, which means that movement into the third quintile involves below-median incomes.

[15] 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.

[16] This is calculated using the average length of a school year – 175 days – during the 1930's (**?**).

[17] Though first discovered several decades prior, the BCG vaccine began to gain acceptance in the United States after World War II (Comstock, 1994). Moreover, the first antibiotic and first bacterial agent effective against tuberculosis were discovered in 1944 (Daniel, 2006).

however, by running the main regressions controlling additionally for pre-iodization prevalence rates of tuberculosis and malaria and the interaction of these dummies with the during and after dummies. These results are reported in Table 7. The pattern of results is overwhelmingly preserved: higher employment, self-employment, and income, but no notable changes in educational attainment.

Table 7: Robustness to Contemporaneous Disease Eradication

	(1)	(2)	(3)	(4)	(5)
	1(Participated in Labor Force)	1(Employed)	1(Self-Employed)	Total Income	Years of Schooling
After x Goiter Rate	0.00269	0.00525**	0.00336	0.0370**	-0.00395
	(0.00253)	(0.00209)	(0.00232)	(0.0169)	(0.0254)
During x Goiter Rate	0.00162	0.00240	0.00540***	0.00671	0.0119
	(0.00212)	(0.00212)	(0.00165)	(0.0119)	(0.0200)
After x Tuberculosis Rate	-0.00156	-0.00127	0.000596	-0.00499	0.0168
	(0.00118)	(0.00105)	(0.00130)	(0.0104)	(0.0178)
During x Tuberculosis Rate	-0.000348	-0.000704	0.000737	-0.00641	0.0158
	(0.00115)	(0.00110)	(0.00115)	(0.00865)	(0.0154)
After x Malaria Rate	0.00191	0.000894	-0.00244	0.0530***	0.113***
	(0.00228)	(0.00194)	(0.00279)	(0.0167)	(0.0386)
During x Malaria Rate	0.00339	0.00246	-0.00149	0.0227	0.0431
	(0.00300)	(0.00303)	(0.00227)	(0.0159)	(0.0312)
Observations	2288838	2288838	1775705	2041381	2046916
Mean of Dependent Variable	0.679	0.652	0.107	8.575	11.37

Notes: Standard errors, clustered by state of residence, 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 1920 state-level female and black proportions interacted with During and After dummies.

We also address the possibility that changes in compulsory schooling laws, implemented at different times across states, may be driving part of the differential changes in labor outcomes that we attribute 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. Since we already include state of birth fixed effects in our regressions, our concern is not with the main effect of these compulsory schooling laws but instead, their interaction with our during and after dummies.

Just as compulsory schooling laws could have driven schooling decisions for our cohorts of interest, it is also known that state mobilization rates for WWII affected labor force participation, particularly for females during this period (Acemoglu et al., 2004). To allow for different state mobilization rates to be driving differential schooling and labor market trends across states, we run our main specification including state of residence mobilization rates as a control, along with years of compulsory schooling interacted with the during and after dummies. Table 8 shows that our main results are robust to the inclusion of all of these controls; our coefficients of interest remain virtually unchanged.

Our final set of robustness tables are aimed at addressing various issues related to the particular goiter variable we use. First of all, although we use continuous goiter as our proxy for iodine deficiency risk, it is not clear that a linear relationship is the most appropriate. In fact, it is known that there is a "protective threshold" for fetal iodine levels, above which normal cognitive functioning is achieved. In order to test for robustness to other representations of our goiter variable that capture this biological feature of fetal iodine, we run our regressions using a discrete indicator for high goiter states. Like Feyrer et al. (2013), we define states as high goiter if they are in the top quartile of the goiter distribution (see Table A1). Table 9 reports regression results for our main outcomes using this discrete goiter variable, and our major conclusions remain unchanged: salt iodization increased employment and self-employment and led to no economically significant changes in educational attainment. Although the after coefficient in the total income regression is still positive, it is smaller in magnitude and no longer significant. It should be noted that switching to a discrete cutoff eliminates any variation in the goiter variable within four of the nine Census divisions, which (due to our inclusion of division-by-birth-year fixed effects) could explain some of these differences.

Other features of the Love and Davenport (1920) data that could be potential sources of measurement error include the non-representative nature of the sample (adult men only) and the fact that only extreme cases of goiter were recorded. We address this by using the Olesen (1929) data to instrument for our Love and Davenport (1920) data, a valid strategy provided that the measurement

Table 8: Robustness to Inclusion of Compulsory Schooling Laws and WWII Mobilization Rates

	(1)	(2)	(3)	(4)	(5)
	1(Participated in Labor Force)	1(Employed)	1(Self-Employed)	Total Income	Years of Schooling
After x Goiter Rate	0.00386*	0.00611***	0.00199	0.0373**	-0.0416*
	(0.00209)	(0.00197)	(0.00184)	(0.0172)	(0.0211)
During x Goiter Rate	0.00134	0.00239	0.00370**	0.0129	-0.00537
	(0.00194)	(0.00206)	(0.00148)	(0.0106)	(0.0176)
After x Compulsory Schooling	0.000701	0.00112	0.000859	-0.00278	-0.0572***
	(0.00108)	(0.000874)	(0.000983)	(0.00748)	(0.0140)
During x Compulsory Schooling	0.00107	0.00149*	0.000819	0.00801	-0.0366***
	(0.000849)	(0.000802)	(0.000573)	(0.00558)	(0.0101)
WWII Mobilization Rate	0.0232	-0.0533	-0.338***	1.745*	4.596**
	(0.0584)	(0.0717)	(0.0936)	(0.918)	(1.785)
Observations	2271262	2271262	1761317	2025548	2031060
Mean of Dependent Variable	0.678	0.652	0.107	8.570	11.36

Notes: Standard errors, clustered by state of residence, 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 1920 state-level female and black proportions interacted with During and After dummies.

Table 9: Robustness to 75th Percentile High Goiter Variable

	(1)	(2)	(3)	(4)	(5)
	1(Participated in Labor Force)	1(Employed)	1(Self-Employed)	Total Income	Years of Schooling
After x High Goiter	0.00341	0.00598*	0.00517*	0.00187	0.0200
	(0.00398)	(0.00351)	(0.00270)	(0.0269)	(0.0521)
During x High Goiter	0.00237	0.00417	0.00548***	-0.00316	0.0202
	(0.00355)	(0.00369)	(0.00192)	(0.0193)	(0.0340)
Observations	2289711	2289711	1776383	2042232	2047767
Mean of Dependent Variable	0.679	0.652	0.107	8.575	11.36

Notes: Standard errors, clustered by state of residence, in parentheses (*** p<0.01, ** p<0.05, * p<0.1). High Goiter is equal to 1 if the goiter rate from the individual's state of birth from Love and Davenport (1920) is in the top quartile of the goiter distribution. 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 1920 state-level female and black proportions interacted with During and After dummies.

error in Love and Davenport (1920) is uncorrelated with that of the Olesen (1929) data, which we argue is a reasonable assumption given the drastically different contexts and methods of data collection. Using a discrete above-median high goiter dummy from Olesen (1929) (interacted with during and after dummies) as instruments for the continuous Love and Davenport (1920) goiter rate (also interacted with those cohort dummies),[18] we run our main regressions in an instrumental variables specification and report the results in Table 10. Overall, the instrumental variables estimates are very similar to the OLS estimates: small negative effects on schooling, but positive effects on employment and self-employment. In the total income regression, both coefficients are negative but statistically indistinguishable from zero, although it should be noted that, for the reasons described above, we lose variation in four regions due to the discrete nature of the instrument. We also have a smaller sample because the Olesen data is missing for 13 states. First stage results are reported in the Appendix (Table A4).

[18]We use this particular discrete variable instead of continuous goiter because it generated the strongest first-stage F-statistic, but the magnitudes of second-stage coefficients were relatively similar across different variations of the Olesen instruments.

Table 10: Instrumental Variables Estimates of the Effects of Salt Iodization

	(1)	(2)	(3)	(4)	(5)
	1(Participated in Labor Force)	1(Employed)	1(Self-Employed)	Total Income	Years of Schooling
After x Goiter Rate	0.00314	0.00813**	0.00626*	-0.0154	-0.161**
	(0.00381)	(0.00408)	(0.00369)	(0.0372)	(0.0741)
During x Goiter Rate	-0.00129	0.00258	0.00837***	-0.0105	-0.0938
	(0.00327)	(0.00380)	(0.00310)	(0.0334)	(0.0702)
Observations	1945695	1945695	1509916	1736654	1741005
Mean of Dependent Variable	0.680	0.653	0.103	8.587	11.44
First Stage F-statistic: (After x Goiter Rate)	13.997	13.997	14.142	14.024	14.014
First Stage F-statistic: (During x Goiter Rate)	13.953	13.953	13.146	13.63	13.637

Notes: Standard errors, clustered by state of residence, 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 1920 state-level female and black proportions interacted with During and After dummies. Instruments used were After x High Goiter (above median) and During x High Goiter (above median) from Olesen (1929).

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 educational attainment and labor force participation. Impacts on educational attainment are concentrated at lower grade levels and amongst residents of states with higher proportions of blue and goods sector employment. These education results are consistent with the improved cognitive ability brought about through salt iodization being a substitute for educational attainment at lower grade levels. Correspondingly, most of the new labor force participants appear to have entered the left tails of the wage and total income distribution.

Our results contribute to several strands of literature and current policy debates. 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 US and other developed settings, can potentially provide important predictions for academic researchers and policy-makers faced with similar issues in developing countries today.

Our study also contributes evidence to a recent body of work investigating the degree to which cognitive ability and formal schooling can substitute for or complement one another at various stages of development. We find that an increase in cognitive ability at the lower end of the skill distribution crowded out primary school completion and drove up labor force participation in low-wage jobs. On the other hand, we find little evidence of an impact of salt iodization on secondary or post-secondary school completion, suggesting that pre-iodization cognitive disadvantages were being compensated for with primary but not higher levels of schooling.

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 .6 percentage point rise in labor force participation, particularly in the second and third 1950 income quintiles. From a base labor force of 52.8 million in 1940 (United States Bureau of the Census, 1944), this amounts to over 3 billion USD in additional wage income using, conservatively, the mean income of those in the third quintile and

lower (52.8 million x 0.006 x 9800 USD = 3.1 billion USD).

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 (as evidenced by the negligible difference between the "during" and "after" coefficients) might be attributable to the efficiency and underlying profit motive of the private firm that undertook the intervention.

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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 and Davenport (1920) (in column 1) and Olesen (1929) (in column 2). We also include their corresponding high-goiter classification using the 75th percentile of the Love and Davenport (1920) distribution as a cutoff in column 3, as well as their classification as a blue collar state in column 4.

Table A1: Regional Classification of States

Census Division	State	(1) Love and Davenport (1920) Goiter Rate *(ppt)*	(2) Olesen (1929) Goiter Rate *(ppt)*	(3) Above p75 Love and Davenport (1920)	(4) 1(Blue Collar State)
New England	Connecticut	0.091	18.2	0	0
New England	Maine	0.056	24.8	0	1
New England	Massachusetts	0.030	1.6	0	0
New England	New Hampshire	0.072	0.2	0	1
New England	Rhode Island	0.055	0.9	0	0
New England	Vermont	0.214	.	0	1
Middle Atlantic	New Jersey	0.043	9.1	0	0
Middle Atlantic	New York	0.118	12.1	0	0
Middle Atlantic	Pennsylvania	0.410	15.5	0	0
East North Central	Illinois	0.780	20.4	1	0
East North Central	Indiana	0.642	76.0	0	1
East North Central	Michigan	1.130	19.6	1	0
East North Central	Ohio	0.568	28.4	0	0
East North Central	Wisconsin	1.384	46.6	1	0
West North Central	Iowa	0.661	.	0	0
West North Central	Kansas	0.124	8.4	0	0
West North Central	Minnesota	0.793	23.6	1	0
West North Central	Missouri	0.398	3.0	0	1
West North Central	Nebraska	0.227	.	0	0
West North Central	North Dakota	0.884	4.0	1	0
West North Central	South Dakota	0.384	.	0	0
South Atlantic	Delaware	0.059	.	0	0
South Atlantic	District of Columbia	0.447	.	0	0
South Atlantic	Florida	0.021	.	0	1
South Atlantic	Georgia	0.050	0.8	0	1
South Atlantic	Maryland	0.094	6.2	0	1
South Atlantic	North Carolina	0.170	0.2	0	1
South Atlantic	South Carolina	0.087	.	0	1
South Atlantic	Virginia	0.333	9.0	0	1
South Atlantic	West Virginia	0.790	43.9	1	1
East South Central	Alabama	0.057	0.1	0	1
East South Central	Kentucky	0.142	6.9	0	1
East South Central	Mississippi	0.057	0.3	0	1
East South Central	Tennessee	0.190	5.2	0	1
West South Central	Arkansas	0.043	.	0	1
West South Central	Louisiana	0.063	5.5	0	1
West South Central	Oklahoma	0.067	10.4	0	0
West South Central	Texas	0.027	.	0	1
Mountain	Arizona	0.110	0.1	0	0
Mountain	Colorado	0.530	35.4	0	0
Mountain	Idaho	2.686	.	1	0
Mountain	Montana	2.097	20.4	1	1
Mountain	Nevada	0.638	.	0	1
Mountain	New Mexico	0.101	0.1	0	1
Mountain	Utah	1.562	44.9	1	0
Mountain	Wyoming	1.538	15.0	1	1
Pacific	Alaska	1.314	.	1	1
Pacific	California	0.438	0.0	0	0
Pacific	Oregon	2.402	22.5	1	1
Pacific	Washington	2.325	17.6	1	0

Table A2 augments our original specification with the addition of a third interaction variable: an indicator for whether an individual lives in a blue collar state, defined by the prevalence of blue collar jobs in their state of residence during the 1920 and 1930 censuses.[19]

Under the assumption that individuals made schooling decisions while in the same state as their current state of residence or had accurate expectations about the type of state they would reside in as an adult, the blue collar dummy acts as a proxy for whether individuals made their schooling decisions with the expectation of taking low-skilled jobs in the future. We therefore expect those living in blue collar states to be the ones driving the substitution results found in Table 6, which is exactly what we find. Column 1 of Table A2 shows us that the effect of salt iodization on primary school completion is negative overall (as we found in Table 6), but significantly more so for those living in a blue collar state. For junior high school completion, the effect is only negative and significant for blue collar states. Again, in both columns 3 and 4, we see that salt iodization did not seem to affect completion of higher levels of schooling in any type of state, blue collar or not, which is consistent with cognitive ability being less substitutable for higher levels of schooling.

[19] We first pool the 1920 and 1930 Censuses and then rank states according to the proportion of individuals working a blue collar job. States with at- or above-median proportions are categorized as "blue collar" states. Column 4 of Table A1 reports each state's binary classification.

Table A2: Effects of Salt Iodization on Education, by State Industry Type

	(1)	(2)	(3)	(4)
	1(Completed Primary)	1(Completed Junior High)	1(Completed High School)	1(Completed College)
After x Goiter Rate x 1(Blue Collar State)	-0.00711***	-0.0106**	-0.0124	0.00309
	(0.00253)	(0.00441)	(0.00981)	(0.00437)
During x Goiter Rate x 1(Blue Collar State)	-0.00645**	-0.0122***	-0.0119	0.00332
	(0.00246)	(0.00450)	(0.00813)	(0.00429)
After x Goiter Rate	-0.00226**	-0.00196	0.00250	-0.00308
	(0.000933)	(0.00155)	(0.00477)	(0.00306)
During x Goiter Rate	-0.000292	0.000757	0.00248	-0.000289
	(0.000783)	(0.00143)	(0.00434)	(0.00235)
After x 1(Blue Collar State)	0.0122**	0.0158*	-0.000911	-0.0131
	(0.00466)	(0.00926)	(0.0202)	(0.00815)
During x 1(Blue Collar State)	0.0140***	0.0222**	0.00102	-0.0141*
	(0.00459)	(0.00907)	(0.0187)	(0.00727)
Goiter Rate x 1(Blue Collar State)	0.0161***	0.0259***	0.0286***	0.000999
	(0.00360)	(0.00522)	(0.0103)	(0.00705)
1(Blue Collar State)	-0.0318***	-0.0496***	-0.0235	0.0126
	(0.00637)	(0.0111)	(0.0216)	(0.00906)
Observations	2047767	2047767	2047767	2047767
Mean of Dependent Variable	0.957	0.903	0.614	0.124

Notes: Standard errors, clustered by state of residence, 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 1920 state-level female and black proportions interacted with During and After dummies.

Table A3: Effects of Salt Iodization on Income by Quintile

	(1)	(2)	(3)	(4)	(5)
	1st Income Quintile	2nd Income Quintile	3rd Income Quintile	4th Income Quintile	5th Income Quintile
After x Goiter Rate	0.00300**	0.00172	0.00248**	0.000617	-0.00384*
	(0.00131)	(0.00104)	(0.000994)	(0.00117)	(0.00206)
During x Goiter Rate	0.00122	0.000920	0.00220**	0.000119	-0.00309
	(0.00120)	(0.00108)	(0.00106)	(0.00126)	(0.00200)
Observations	2042232	2042232	2042232	2042232	2042232
Mean of Dependent Variable	0.108	0.102	0.0877	0.0972	0.411

Notes: Standard errors, clustered by state of residence, 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 1960 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 1920 state-level female and black proportions interacted with During and After dummies.

Table A3 reports coefficients from the quantile dummy regressions that are graphically illustrated in Figure 5. Note that the means of the dependent variables do not sum to one because individuals earning no income were assigned a zero for all five dummies (See section B for details on the construction of these variables.)

Table A4 reports the first-stage regressions for the instrumental variables specification reported in Table 10, which uses a discrete above-median high goiter variable from the Olesen (1929) data (interacted with during and after dummies) to instrument for the continuous goiter rate from Love and Davenport (1920) (also interacted with the cohort dummies).

Table A4: First Stage Results for Instrumental Variables Estimates of the Effects of Salt Iodization

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Labor Force, Employment		Self-Employment		Income		Education Outcomes	
	After x Goiter Rate	During x Goiter Rate	After x Goiter Rate	During x Goiter Rate	After x Goiter Rate	During x Goiter Rate	After x Goiter Rate	During x Goiter Rate
After x High Goiter (Olesen Data)	0.864***	-0.00346	0.866***	-0.00369	0.869***	-0.00453	0.869***	-0.00443
	(0.169)	(0.00840)	(0.172)	(0.00796)	(0.168)	(0.00800)	(0.168)	(0.00801)
During x High Goiter (Olesen Data)	-0.00110	0.859***	-0.000134	0.859***	-0.00121	0.862***	-0.00110	0.862***
	(0.00713)	(0.168)	(0.00699)	(0.172)	(0.00685)	(0.167)	(0.00683)	(0.167)
Observations	1945695	1945695	1509916	1509916	1736654	1736654	1741005	1741005
Mean of Dependent Variable	0.196	0.204	0.205	0.206	0.197	0.206	0.197	0.206
F-statistic for excluded instruments	13.997	13.953	14.142	13.146	14.024	13.63	14.014	13.637

Notes: Standard errors, clustered by state of residence, in parentheses (*** p<0.01, ** p<0.05, * p<0.1). 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 1920 state-level female and black proportions interacted with During and After dummies. High Goiter (Olesen Data) is equal to 1 for individuals born in states in the top half of the goiter distribution from Olesen (1929).

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);
  1(Participated in Labor Force)=0 if the individual did not participate in the labor force.
- *1(Employed)*=1 if the individual was employed;
  1(Employed)=0 if the individual did not work, irrespective of whether the individual looked for a job.

- *1(Self-Employed)*=1 if the individual was self-employed;
  1(Self-Employed)=0 if the individual worked for wages as an employee.

- *Total Income*: This is the inverse hyperbolic sine of the total annual income earned by the individual (for those earning positive total income) and zero for those who earned zero income. 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.

- *1(Completed Primary School)*=1 if the individual completed 6 or more years of schooling.
  1(Completed Primary School)=0 if the individual completed less than 6 years of schooling.

- *1(Completed Junior High)*=1 if the individual completed 8 or more years of schooling.
  1(Completed Junior High)=0 if the individual completed less than 8 years of schooling.

- *1(Graduated High School)*=1 if the individual graduated high school. This includes those who completed the GED but not those who went to vocational school ;
  1(Graduated High School)=0 if the individual did not complete high school.

- *1(Graduated College)*=1 if the individual graduated from college;
  1(Graduated College)=0 if the individual did not complete college.

B.2.2 Income Quintile Analysis

1(Total Income Quintile 1) to *1(Total Income Quintile 5)* were constructed as follows. Using the entire population aged 25-55 from the 1950 Census, we calculate the 20th, 40th, 60th, and 80th percentiles for log income. These were used as the baseline quintiles to construct the following variables:

- *1(Total Income Quintile 1)*=1 if the individual's log income was greater than zero and fell into the first quintile of *Total Income* from the 1950 Census ; *1(Total Income Quintile 1)*=0 if the individual's log income fell outside of this first quintile or was equal to zero. This variable is missing for those with missing total income in the Census. Analogous variables are constructed for the second,

third, fourth, and fifth quintiles. For each individual, at most only one of these five variables is set equal to one. For those with zero income, all of the dummies are set equal to zero.

B.3 Other Variables

- *female*=1 for females; *female*=0 for males
- *black*=1 for black individuals; *black*=0 for all other races
- *femaleprop1920*: The state-level proportion of the population that was female in the individual's state of residence (as reported in the 1920 Census).
- *blackprop1920*: The state-level proportion of the population that was black in the individual's state of residence (as reported in the 1920 Census).
- *1(Blue Collar State)*=1 if individual resides in a state that, according to the 1920 and 1930 Censuses, had an at- or above-median proportion of individuals working at a blue-collar job
  1(Blue Collar State)=0 if individual resides in a state that had a below-median proportion of individuals working at a blue-collar job (according to the 1920 and 1930 Censuses). Blue collar jobs were identified using the *occ1950* occuptation codes from the Census.
- *Tuberculosis*: Pre-iodization tuberculosis rate in state of birth according to Love and Davenport (1920)
- *Malaria*: Pre-iodization malaria 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)
- *Mobilization Rate*: WWII mobilization rate for individual's state of residence

B.4 State-Level Goiter Rates from Olesen (1929)

Olesen (1929) reports goiter rates in various localities for 37 states. For each of these localities, there is a column for boys, a column for girls, as well as a column for boys and girls. For each of these columns, he reports the percent found with goiter and in some cases, also the number of children

examined. Because the number of children examined is missing for over 400 localities, and also because weighting by this number would be artificial (since we do not have locality populations, which would be the ideal), we calculate the simple mean of the percentages across all localities within a state for each column. Our goiter rate of interest is the state-level goiter rate in the boys and girls column. For states which have no percentages reported in the boys and girls column, we take the average across the boys column and the girls column. For those that only have a boys column or a girls column, we use the state average of the non-missing column.

C Model

In a standard model of educational attainment (Card, 2001), a cognitive shock can increase or decrease schooling depending on whether it affects the interaction between ability and schooling or ability endowments independent of schooling. We present the model in Card (2001) to show that cognitive ability shocks can decrease educational attainment at low levels of schooling if the there is heterogeneity in initial wage levels. The intuition is straight-forward. If an ability shock increases the starting wage for any amount of schooling, then lifetime income can increase with less schooling as the additional time earning wages in the labor force makes up for the loss of the return to additional schooling. This is particularly pronounced when the return to schooling is low. If there is a direct utility cost of attending school, then there is further downward pressure on educational attainment.

This point has been made before (Griliches, 1977), but it appears that most researchers are more concerned about the upward bias in returns to schooling regressions caused by an interaction between ability and schooling. Our intention is to show that the negative effect on schooling is consistent with a standard model of educational attainment with some slight modifications.

Card (2001) models the educational attainment choice as a lifetime utility maximization problem. Utility depends on consumption, c(t), and a distaste for schooling, $\phi(t)$, while in school and consumption once schooling is completed. Future utility flows are discounted at rate ρ so that utility conditional on years of education, S, is

$$V\left(S, c\left(t\right)\right) = \int_0^S \left(u\left(c\left(t\right) - \phi\left(t\right)\right)\right) e^{-\rho t} dt + \int_S^\infty u\left(c\left(t\right)\right) e^{-\rho t} dt.$$

Utility is maximized subject to a budget constraint that consumption is equal to income, discounted at interest rate R as follows,

$$\int_0^\infty c\left(t\right) e^{-Rt} dt = \int_S^\infty y\left(S, t\right) e^{-Rt} dt,$$

where y(S,t) is earnings at age t for someone with S years of schooling.[20]

We will ignore the direct utility cost of schooling as this is not necessary to produce the result. Setting up the lagrangian and taking the derivative with respect to S gives the condition for optimal

[20]Card (2001) also allows for earnings while in school and tuition costs, which are likely to be negligible for low levels of schooling and are thus ignored.

schooling,

$$\lambda e^{-RS}\left\{\int_0^{\infty}\frac{\partial y\left(S,S+\tau\right)}{\partial S}e^{-R\tau}d\tau-y\left(S,S\right)\right\}=0$$

Card (2001) assumes that the log of the earnings function is additively separable in years of schooling, S, and experience, (t - S). That is, y(S,t) = f(S)h(t - S). A final assumption is that h(0) = 1. y(S,S) simplifies to f(S) in this case and the optimal schooling expression becomes

$$f'(S)\int_0^{\infty}h\left(\tau\right)e^{-R\tau}d\tau=f(S).$$

Card (2001) models the return to experience function, $h(\tau)$, with a constant growth rate, g, so that

$$\int_0^{\infty}h\left(\tau\right)e^{-R\tau}d\tau=\int_0^{\infty}e^{-(R-g)\tau}d\tau=\frac{1}{R-g}$$

Optimal schooling thus satisfies the condition

$$\frac{f'(S)}{f(S)}=R-g.$$

Card (2001) assumes that $\frac{f'(S)}{f(S)}$ is linear in S, so that $log(y)=a_i+b_iS_i-\frac{1}{2}k_1S_i^2$, or $f(S)=e^{a_i+b_iS_i-\frac{1}{2}k_1S_i^2}$. Heterogeneity in wages due to ability endowments, a_i, drops out of the optimality condition. That is, $\frac{f'(S)}{f(S)}=b_i-k_1S_i$. This feature is solely due to the functional form assumption.

If we do not allow the heterogeneity in initial earnings levels to be additively separable in the log, so that $f(S)=a_i+e^{b_iS_i-\frac{1}{2}k_1S_i^2}$, we get

$$\frac{f'(S)}{f(S)}=\left(b_i-k_1S_i\right)\frac{e^{b_iS_i-\frac{1}{2}k_1S_i^2}}{a_i+e^{b_iS_i-\frac{1}{2}k_1S_i^2}}=R-g.$$

A cognitive ability shock that increases a_i will decrease the optimal amount of schooling. Note that an increase in a_i decreases the left hand side of the optimality equation. Schooling needs to adjust to increase the left hand side back up to R - g. The left hand side must therefore be a decreasing function of S.

$$\frac{\partial}{\partial S} = \frac{\left(a_i + e^{b_i S_i - \frac{1}{2}k_1 S_i^2}\right)\left((b_i - k_1 S_i)^2 e^{b_i S_i - \frac{1}{2}k_1 S_i^2} - k_1 e^{b_i S_i - \frac{1}{2}k_1 S_i^2}\right) - (b_i - k_1 S_i)^2 \left(e^{b_i S_i - \frac{1}{2}k_1 S_i^2}\right)^2}{\left(a_i + e^{b_i S_i - \frac{1}{2}k_1 S_i^2}\right)^2}$$

$$= \left(e^{b_i S_i - \frac{1}{2}k_1 S_i^2}\right)\left(\frac{\left(a_i + e^{b_i S_i - \frac{1}{2}k_1 S_i^2}\right)\left((b_i - k_1 S_i)^2 - k_1\right) - (b_i - k_1 S_i)^2 e^{b_i S_i - \frac{1}{2}k_1 S_i^2}}{\left(a_i + e^{b_i S_i - \frac{1}{2}k_1 S_i^2}\right)^2}\right)$$

$$= \left(e^{b_i S_i - \frac{1}{2}k_1 S_i^2}\right)\left(\frac{a_i (b_i - k_1 S_i)^2 - k_1\left(a_i + e^{b_i S_i - \frac{1}{2}k_1 S_i^2}\right)}{\left(a_i + e^{b_i S_i - \frac{1}{2}k_1 S_i^2}\right)^2}\right)$$

This expression is negative when

$$k_1\left(a_i + e^{b_i S_i - \frac{1}{2}k_1 S_i^2}\right) > a_i (b_i - k_1 S_i)^2 .$$

As long as this expression holds, then a shock that increases ability endowments will decrease educational attainment. It is sufficient to show that this holds when $k_1 f(S) > a_i (f'(S))^2$, which is likely when the return to schooling is low. The left hand side is proportional to the wage given an amount of schooling and the right hand side is proportional to the square of the marginal return at that level of schooling. Given a higher initial wage and constant wage growth, the return from an additional year of schooling does not make up for having fewer years of wages.

If we add disutility of schooling back into the model, Card (2001) shows that the optimality condition becomes

$$\frac{f'(S)}{f(S)} = R - g + \rho e^{-\rho S}\phi(S).$$

Since the right hand side is an increasing function of S, a positive shock to ability endowments puts further downward pressure on S. Now, there is an additional direct utility cost of attending school in addition to giving up a year of earnings.

Given the assumption that the log of the earnings function is additively separable in education and experience, it is also straight forward to show that an ability shock that increases the return to

experience has a dampening effect on schooling.

In the context of our paper, the individuals most likely to benefit from salt iodization were those on the bottom end of the IQ spectrum who were marginally attached to the labor market and who would otherwise have attained minimal schooling where the wage returns are relatively low. These individuals are more likely to gain employment in blue collar work. It is likely that there are both ability endowment effects and a higher capacity to learn on the job due to the presence of iodized salt. It is less likely that the cognitive shock worked through the interaction of ability and schooling, b_i, which increases educational attainment even with the change in functional form.