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The Economic Effects of Micronutrient Deficiency: Evidence from Salt Iodization in the United States

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February 26, 2010
Preliminary Work

Abstract

Iodine deficiency is the leading cause of preventable mental retardation in the world today. Iodine deficiency was common in the developed world until the introduction of iodized salt in the 1920's. The incidence of iodine deficiency is connected to low iodine levels in the soil and water. We examine the impact of salt iodization in the US by taking advantage of this natural geographic variation. Areas with high pre-treatment levels of iodine deficiency provide a treatment group which we can compare to a control group of low iodine deficiency areas. In the US, salt was iodized over a very short period of time around 1924. We use previously unused data collected during WWI and WWII to compare outcomes of cohorts born before and after iodization, in localities that were naturally poor and rich in iodine. We find evidence of the beneficial effects of iodization on the cognitive abilities of the cohorts exposed to it.

1 Introduction

Public health interventions in developing countries have lately been the center of media attention and scholarly work. This interest is justified by the potentially significant impact of large-scale health interventions on people's productivity, longevity, and quality of life. Improvements in productivity and life expectancy could have strong positive effects on developing countries' economic growth, while differences in access to health might help explain a big part of income gaps between countries.[1] It is interesting to note that many of the health problems faced by developing countries were only recently solved in the developed world. Many authors have therefore

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[1]For instance, Sachs (2003) shows that efforts to eliminate malaria have substantial effects on income, through their effect on health, reduced absenteeism, etc. Acemoglu and Johnson (2007) look at the effect of health interventions and find little effect. Weil (2007) charts a middle course.

turned to the historical experience of currently developed countries in order to estimate the potential benefits of health interventions.[2]

Micronutrient deficiencies are widespread in developing countries, and in the last decades a global effort has been launched to ameliorate them. However, little evidence exists about the aggregate, long-run effects of such interventions on either population health or economic measures such as labor productivity.[3] In this paper we address these issues by looking to the history of the United States, which like many other developed countries, undertook early in the 20th century interventions similar in scope and intent to those being applied in developing countries today. In particular, we examine the iodization of salt.

Severe iodine deficiency in utero is known to cause significant development damage, including decreases in cognitive ability. Iodine deficiency is linked directly to geography through the food and water supply. In adults, the most noticeable symptom of iodine deficiency is goiter, the enlargement of the thyroid gland. Prior to salt iodization, endemic goiter and other iodine deficiency disorders were present in specific regions of the US and absent from others, depending on the iodine content of the soil and water. Figure 1 illustrates the geographic distribution of goiter in the US as measured among World War I recruits (we discuss the data further below). In 1924 iodized salt was introduced in the United States explicitly to reduce the goiter rate. This intervention rapidly reduced the incidence of iodine deficiency.

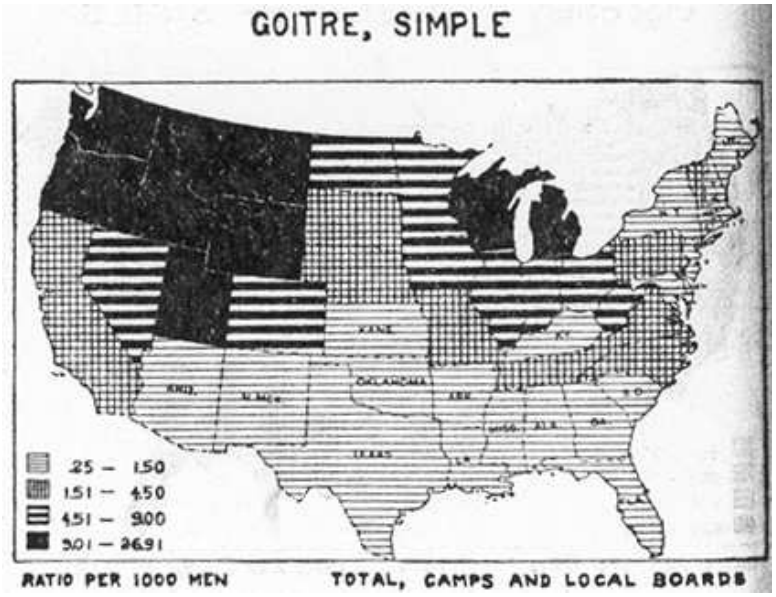
Iodization of salt in the US provides a particularly good natural experiment due to the geographic distribution of the disease combined with a rapid, complete treatment. Since there are large in utero effects of iodine deficiency, we should see a significant difference between those born before and after the introduction of iodized salt in locations with low levels of environmental iodine. Those living in high iodine regions provide a control group.

We exploit two unique data sources to look at the effects. After World War I, statistics from draft physicals were compiled by geographic location. From this source we know the incidence of goiter for 151 geographic regions before the introduction of iodized salt. This provides us with a pretreatment measure of iodine deficiency.

[2]For example, Bleakley (2007) examines the effects of hookworm eradication in the American South in early 20th century and finds significant effects on education and future incomes of those cohorts that benefited from the intervention. Also, Watson (2006) finds that improvements in sanitation of Indian reservations in the 1960's explain a big part of the convergence in infant mortality rates between Whites and Native Americans.

[3]The only study that we know of examining the effect of iodization is Field, Robles, and Torero (2007). They find that in Tanzania, treatment of mothers with iodated oil resulted in a rise in schooling of 0.33 years among children, with a larger effect for girls than boys.

Figure 1: Distribution of Goiter during WWI



source: *Defects found in Drafted Men (Love 1920)*

Our outcome measure is provided by an extensive dataset of men who enlisted in the Army during World War II. The timing of the war generates a large sample of men born in the years 1920-1927, neatly covering the introduction of iodized salt. Upon enlistment, each recruit took the Army General Classification Test (AGCT), a forerunner to the AFQT. The Air Corps was assigned draftees with significantly higher average test scores than the ground forces. We exploit this fact to get a crude estimate of each recruit's AGCT score based on their assignment.

The probability of assignment to the Air Corps rises significantly in low iodine (i.e. high goiter) counties in the years after the introduction of iodized salt. In the lowest iodine regions, our estimates suggest a 10-20 percent increase in the probability of a man being assigned to the Air Corps after iodization.

Using information about average scores of Air and Ground Force recruits we can infer a one-quarter to one half standard deviation increase in average test scores in these regions. The average level of iodine deficiency in the US was significantly lower than in the highest regions, so the overall effect in the US was much more modest, though iodization was undoubtedly extremely cost effective. The increase in cognitive ability due to salt iodization may have contributed a small amount to trend rise in measured IQ that took place over the course of the twentieth century,

the so-called Flynn Effect.

The paper proceeds as follows: section 2 provides some background on iodine deficiency disorders. Section 3 outlines the history of salt iodization in the US. Section 4 describes our data and provides some background on their collection. Section 5 explains our identification strategy and section 6 presents our results. Section 7 interprets our results and puts them in the context of related research on the effects of iodization. Section 8 concludes.

2 Iodine Deficiency Disorders

Recent work has shown that the quality of maternal health and nutrition during pregnancy has persistent effects on adult health outcomes. For instance, Almond (2006) shows that cohorts exposed to the Spanish Influenza of 1918, either in utero or during the first months of life, had worse health and socio-economic outcomes in their lifetime. Behrman and Rosenzweig (2004) find that differences in birth weight among identical twins are reflected in differences in school attainment and adult earnings.[4]

Iodine is one of the "big three" micronutrients, deficiencies in which are a major source of ill health in developing countries (the other two are vitamin A and iron). Iodine deficiency, in particular, is the leading cause of preventable mental retardation in the world. WHO estimates that nearly 50 million people suffer some degree of mental impairment due to iodine deficiency[5]. Two billion people -one third of the world's population- are at risk, in the sense that their iodine intake is considered insufficient. According to WHO's Global Database on Iodine Deficiency, more than 285 million children receive inadequate amounts of iodine in their diet (de Benoist, Andersson, Egli, Takkouche and Allen, eds 2004).

Iodine Deficiency Disorders (IDD) is a term used to describe a range of anomalies, ranging from goiter to cretinism, due to inadequate provision of iodine. Iodine is a micronutrient essential for the synthesis of the two thyroid hormones, thyroxine and triiodothyronine. These hormones are necessary for metabolism, the neuromuscular system and the reproductive function.

Around 70-80% of the total iodine content in the human body is found in the thyroid gland (Fleischer, Forbes, Harriss, Krook and Kubota 1974). The thyroid gland uses iodine to produce thyroxin, a hormone that regulates the metabolism. When there is too little iodine in the diet, the thyroid enlarges, forming a goiter. This

[4]More cites to be added, including Case & Paxson.

[5]source: WHO, http://www.who.int/features/qa/17/en/index.html.

enlargement (governed by thyroid stimulating hormone produced by the pituitary gland in response to low thyroxin) allows the thyroid to produce more thyroxin for a given availability of iodine, and can fully or partially compensate for the shortage of iodine. When dietary iodine is only slightly inadequate, the enlarged thyroid will be able to produce sufficient thyroxin for normal body functioning. This is known as euthyroid goiter. At lower levels of dietary iodine, the enlarged thyroid will produce inadequate thyroxin, a condition known as hypothyroid goiter, characterized by slow metabolism, lethargy, and weight gain.

In most individuals with goiters due to iodine deficiency, an increase in dietary iodine will result in the thyroid gland returning to its normal size and thyroxin production remaining at or returning to its proper level. However, in some people with this condition, increased iodine consumption results in the thyroid glad producing excessive quantities of thyroxin, resulting in hyperthyroidism. This is called iodine-induced thyrotoxicosis. Hyperthyroidism is characterized by a too-fast metabolism, with symptoms including rapid heartbeat, weight loss, temperature elevation, nervousness, and irritability[6][7]. The problem of iodine induced thyrotoxicosis is most likely to occur in individuals who have experienced long periods of iodine deficiency and those with "nodular goiter". Nodular goiter represents a later stage of the disease; it is preceded by diffuse enlargement or simple goiter[8].

Beyond goiter and the associated effects of iodine on the metabolism, a second effect of iodine deficiency is in utero. Iodine deficiency early in pregnancy causes serious brain damage to the foetus. Unlike the effects of goiter, this damage is permanent. Severe iodine deficiency can result in cretinism, which is characterized by "profound mental deficiency, dwarfism, spastic dysplasia and limited hearing" (Scrimshaw 1998, p.364)[9]. However, as Scrimshaw points out, "even in areas where cases of cretinism due to iodine deficiency in the mother are few, the linear growth of the infant, its intellectual capacity, and certain other of its neurological functions are permanently compromised to varying degrees" (Scrimshaw 1998, p.351). In other words, even if iodine deficiency does not result in cretinism, an iodine-deficient re-

[6]Reference: "Goiter" in Health A to Z, www.healthatoz.com

[7]Goiter and hyperthyroidism can also result from Graves Disease, also called Basedow disease, an immune condition in which the thyroid is stimulated to produce excess thyroxin.

[8]Iodine-induced thyrotoxicosis is also called Jod-Basedow disease. "Jod" is German for iodine. The name indicates that iodine consumption is resulting in the symptoms of Basedow disease. Examining the rise in thyroid disease that followed the introduction of iodized bread in Tasmania, Connolly (1971) found that most patients with iodine-induced thyrotoxicosis had pre-existing nodular goiter, and few had Graves disease.

[9]According to one interpretation, the word cretin comes from the French term for Christian. Cretinism was endemic in the French Alps, where the term was apparently invented for those who were too dumb to commit a sin and who, therefore, were good Christians.

gion will be marked by the lower cognitive performance of its population. Typically, non-deficient populations differ from iodine-deficient populations by approximately 10 IQ points, whereas the whole normal IQ distribution of a population shifts to the left as a result of iodine deficiency[10]. In endemic areas, cretinism can affect up to 15% of the population (de Benoist et al., eds 2004). Bleichrodt and Born (1994) estimate that the average IQ of iodine-deficient groups is 13.5 points lower than the non-deficient groups. If this is true, then iodine deficiency should have sizable economic effects for any affected population.

In economies where the diet is composed primarily of locally produced food, the main determinant of whether a population will be iodine-deficient or not is a region's geography. Ocean water is rich in iodine, which is why endemic goiter is not observed in coastal areas. From the ocean, iodine is transferred to the soil by rain. This process, however, only reaches the upper layers of soil, and it can take thousands of years to complete (Koutras, Matovinovic and Vought 1980). Heavy rainfall can cause soil erosion, in which case the iodine-rich upper layers of soil are washed away. The last glacial period had the same effect; iodine-rich soil was substituted by iodine-poor soil from crystalline rocks (Koutras et al. 1980). This explains the prevalence of endemic goiter in regions that were marked by intense glaciation, such as Switzerland and the Great Lakes region. Iodine is taken up by plants when it is present in the soil, and can reach humans either through plants or animals which have eaten them. Iodine is also present in subsurface water in some locations. Finally, deposits of mineral salt (the remains of evaporated seawater) contain iodine, but this is lost when the salt is refined. The human body does not naturally store a great deal of iodine, so that seasonal variations in iodine consumption may result in seasonal manifestations of IDD.

Even before the discovery of iodine, ancient civilizations treated goiter with burnt sponge or seaweed (Curtis and Fertman 1951, Langer 1960). After iodine was discovered in 1811 by Courtois, continuous clinical research for over a century proved its essential role as a measure of prophylaxis against IDD. Doctors and public health officials have used different ways to ensure that adequate quantities of iodine are provided for a given population. Salt iodization has proved to be the cheapest and most wide-reaching way to protect a population from iodine deficiency. Alternatives have included the iodization of water supplies and bread, as well as the provision of iodine-enriched chocolates or milk to babies and schoolchildren and injections of slow-releasing iodated oil[11].

[10]Scrimshaw (1998) provides a list of studies and experiments that have been conducted, and which have shown the hindering effects on mental development of iodine deficiency in utero.

[11]Iodization of water supplies proved wasteful since only a small proportion of water is used

3 Iodine Deficiency and Salt Iodization in the United States

It was only in the last century that micronutrient deficiency diseases were eliminated in the United States and other developed countries. Pellagra, a deficiency in niacin that results from diets dependent on maize, was endemic in the US South at the beginning of the twentieth century. Rickets, a bone-deforming disease caused by deficiency of vitamin D, was common in industrial cities of the North. Both diseases were controlled by a combination of dietary improvements and fortification. Vitamin D was added to milk in the 1930s, and B vitamins (including niacin) were added to fortified baked goods starting in the 1940s (Bishai and Nalubola 2002).

Salt iodization was the first experiment in the systematic fortification of food to combat micronutrient deficiency. This public health intervention was made possible by the nearly simultaneous discovery of a widespread health problem and of its underlying cause.

In the First World War draft, a little more than 2.5 million draftees were examined for various physical and mental shortcomings. From these examinations, a lengthy collection of countrywide data was compiled, showing the geographic distribution of many diseases and defects across the United States (Love and Davenport 1920). Goiter was among the defects that were measured, because an unexpectedly high number of soldiers had trouble wearing a uniform because of their enlarged thyroids.

According to the draft examinations, almost 12,000 men had goiter and a third of these were judged unfit for service, because the size of their neck was too big for the military tunic to be buttoned (Kelly and Snedden 1960, p.34). Most of them came from states in the Northwest (Washington, Oregon, Idaho, Montana) and the area around the Great Lakes. In Northern Michigan, for instance, more draftees were judged unfit for service "for large and toxic goiters than for any other medical disorder" (Markel 1987, p.221). On the other hand, goiter was rare in people coming from coastal areas.

The realization of the problem led to multiple surveys of goiter, which confirmed the geographical variation in the prevalence of goiter. By that time, there was medical and veterinary evidence showing that goiters could be reduced by adding iodine to the diet. Experiments with school children confirmed that the size of goiters decreased after receiving iodine[12]. These observations prompted a public debate on

for drinking and cooking purposes. Bread iodization was used in the Netherlands as a wartime measure (Matovinovic and Ramalingaswami 1960).

[12]The first such experiment took place in Akron, Ohio in 1917, under the direction of David

the possible ways to provide iodine prophylaxis to the American population. Some objections were raised as to the potential side-effects of such a global measure. It had been documented that large amounts of iodine could cause hyperthyroidism to develop in some adults and thyrotoxicosis in others[13]. Despite these concerns, the medical consensus was that small amounts of iodine in the diet were beneficial for the vast majority of an iodine-deprived population, and this was confirmed by the experimental results in schoolchildren.

Public health authorities in Michigan, one of the worst-afflicted states, held a symposium on thyroid disease in 1922. The idea of salt iodization (which had been proposed by researchers in Switzerland, and was first implemented in that country in 1922) was introduced by David Murray Cowie, M.D. as a cheap and effective means of providing iodine to all population groups, regardless of social status. As a result, the Iodized Salt Committee was set up, with the mission of investigating the matter further. The Committee, chaired by Cowie, produced reports on the low iodine content of drinking water in Michigan and the possibility of effective prevention of goiter though iodized salt. Its members agreed upon the launch of a statewide educational campaign on goiter and its prevention though iodized salt, sponsored by the Michigan State Medical Society. The campaign, launched in 1922, included lectures to physicians and the general public delivered across the state.

The Committee also contacted the state's salt manufacturers. The salt producers, although convinced about the public-service character of the project, had initial qualms about its economic feasibility and profitability; it would be financially impossible to separate the salt intended for the Michigan market and then add iodine to it. Instead, the Salt Producers Association decided to launch iodized salt nationwide; they saw the new product as an improved commodity for which there would be a much larger market -and corresponding profits- than that of Michigan. As a result, in May 1924, Michigan was the first state to introduce iodized salt[14]. The actions of the Michigan salt producers were important, because Michigan was the largest producer of salt for human consumption in the country[15].

Marine and O.P. Kimball. For details see Marine and Kimball (1921), and Carpenter (2005).

[13]Thyrotoxicosis might occur as a result of iodization in those individuals that have suffered from long-term iodine deficiency and whose goiters have become nodular. In such cases, iodine supplementation causes the output of hormone to jump to toxic levels.

[14]Before that, in April 1923, public authorities in Rochester, New York, introduced iodine in the water supplies of one reservoir, in what is known as "the Rochester experiment" (Kohn 1975). Subsequent goiter surveys show an important decrease in incidence. However, it seems unlikely that this decrease was due to the iodization of the water supply, for the following reasons: first, only one of the reservoirs was iodized. Second, by that time, iodized salt was available and widely used in Rochester. Third, because of bigger awareness and improved medical monitoring, doctors were more likely to prescribe iodine supplements to anybody with a palpable goiter.

[15]Salt production takes three forms: evaporated, rock salt, and the production of liquid brine.

The salt companies contributed to the educational campaign through aggressive advertising of the "new salt" throughout the country, in order to create a market for the new product (Markel 1987, p. 224). Figures 2 and 3 shows two ads from this period. Figure 4 is a copy of a newspaper clipping from the era.

After Michigan introduced iodized salt, the penetration of the new product statewide was quite rapid. As mentioned above, salt producers made the new product available nationwide, since this was the only way that the project would be financially feasible. The Morton Salt Company, the largest producer in the country at the time, began selling iodized salt on a nationwide basis in the fall of 1924 [16]. At the same time, public awareness of the problem, especially in those areas that were afflicted the worst, was gaining momentum. Articles in newspapers and magazines around the country advocated the use of the new salt for all cooking and eating purposes, making references to successful goiter prophylaxis in Switzerland[17]. Most state health authorities urged the public to use iodized salt. In advertisements of iodized salt, the new commodity bore the endorsement of state or national medical associations and educational booklets were provided by the salt companies upon demand. We have not been able to find precise numbers on the penetration of iodized salt (or other iodine dietary supplements) for the rest of the country, but all the evidence suggests that the new product became very popular very quickly, especially in the goiter-belt region, where it mattered the most. We have many newspaper sources that show the generalized availability and use of iodized salt from 1924 onwards.

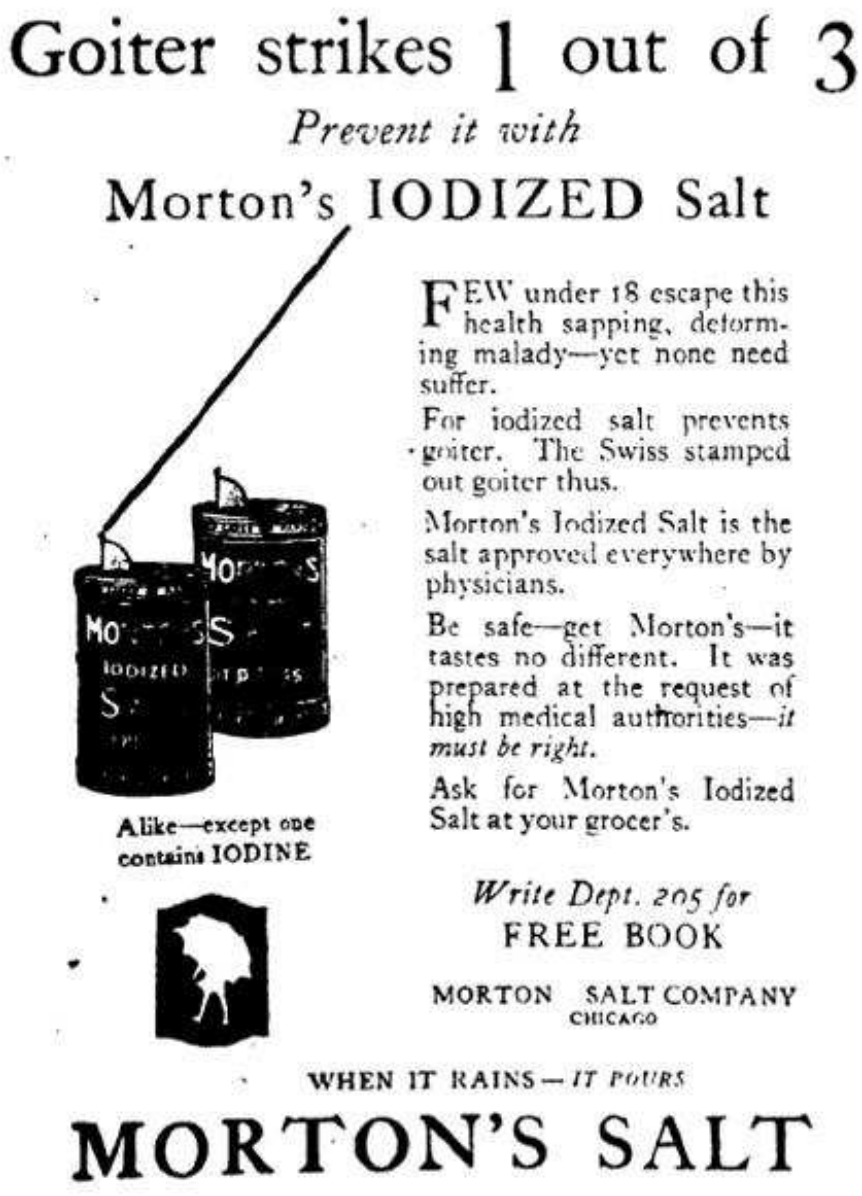
The focus of the salt iodization campaigns was goiter eradication. This is sensible given goiter's obvious physical symptoms. It is not clear that the link between iodine deficiency and mental function was suspected at the time. The decrease in mental retardation that we suspect resulted from iodization campaigns was a very

In 1924 the quantities produced by these three methods were 2.22, 2.06, and 2.51 million short tons, respectively. Brine was used exclusively as a feedstock by the chemical industry. According to the Salt Institute (http://www.saltinstitute.org), as of today, virtually all food grade salt sold or used in the United States is produced by evaporation. This was the case in 1924 as well (personal communication from Richard Hanneman, president Salt Institute, March 6, 2008). In 1924, Michigan was the largest producer of evaporated salt in the country, accounting for 36% of the total. The next largest producers were New York (18%) and Ohio (14%) (Katz 1927).

[16](Markel 1987). Collusion in the evaporated salt industry was widespread, and Morton acted as the price setter. Many companies literally made copies of Morton's price schedule, simply replacing their company letterheads for that of Morton (Fost 1970). Morton's decision to iodize salt in 1924 would thus likely have affected a large percentage of households, both directly and through Morton's influence on smaller companies.

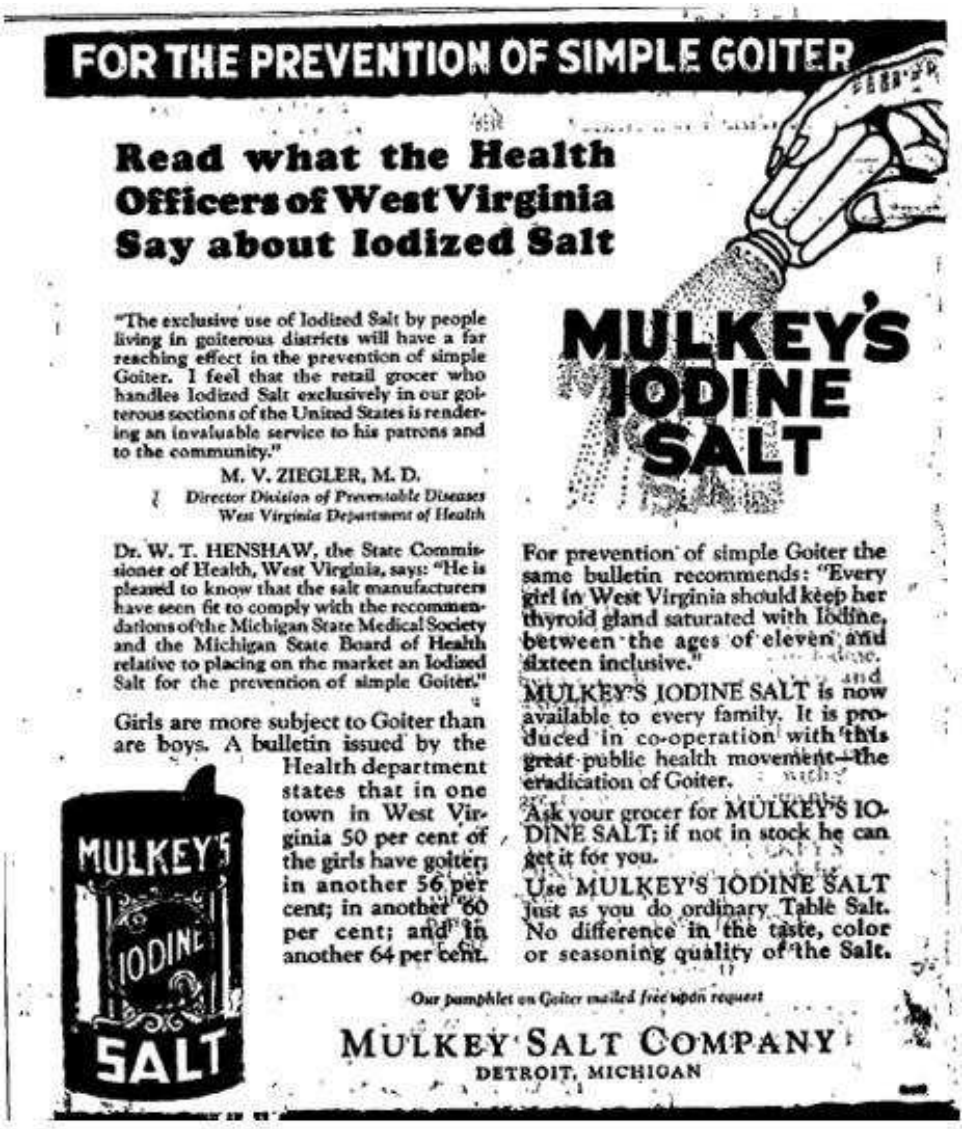
[17]For example: Lima News (Lima, Ohio), on August 29, 1924, reports that iodized salt is now marketed "thru the regular grocery trade". In Appleton Post Crescent (Appleton, Wisconsin), on January 28, 1926, it is mentioned that "iodized salt is now sold by grocers everywhere, and families can use it instead of ordinary salt". More sources are available from the authors upon request.

Figure 2: Ads for Iodized Salt



Source: *"The Bee"*, Danville, Virginia, May 11th 1925

Figure 3: Ads for Iodized Salt



Source: "Middlesboro Daily News", Kentucky, June 14th 1924

Figure 4: A Newspaper Article Discussion of Iodized Salt

Iodized Salt Now in General Use

New Way of Putting Iodine Into Food.

Do you ever pay particular attention in some of Decatur's restaurants when the waiter slips up and fills the salt shaker? If you have you probably have noticed that often the carton from which the salt is sifted into the shaker is labelled "iodized salt." And having seen it did you ever wonder why?

Restaurants use it because of an ever increasing demand for iodized salt in the food, and its use is a prevention of disease.

CAN DO NO HARM.

"I am glad to see it used," said Dr. Keister Monday morning when the matter was mentioned to him. "I do not know that I had noticed its use, but it can do no harm as I see it and its use may do much good. Iodine is recommended for use in cases of simple goiter and some splendid results have been reported in its use."

This section of the country, he explains is known for the great number of goiter cases, and a large per cent of the children in the schools have enlarged thyroids. Iodine is gone from the land here and therefore from the water. At the sea shore there rarely is a case of goiter developed. Mountain regions and lake regions and inland regions have many cases, it is believed because of this lack of iodine in the food and the water.

FROM SEA WEED.

Oysters and all kinds of sea food contain iodine, and the iodine itself is obtained from sea weed, and a Japanese sea weed in particular. As a rule the farther distant a section is from the sea the greater the amount of goiter.

There are three ways of administering it and by salt is the simplest. It merely puts into the food what it has failed to obtain from the land or water. Another way is to administer it medicinally and the third is by use in drinking water.

GIVEN TO CHILDREN.

In Akron, O., some very fine results have been obtained by giving it to school children. It was given over a period of ten years and the results watched. One half of the 10,000 children were given it twice a year. Among those to whom it was administered who were in a normal condition, not one developed goiter. Among those who did not take it 27.6 developed goiter in some form. Others who had the trouble but who took it showed that sixty per cent returned to normal condition.

Source: *"The Decatur Review"*, Illinois, December 1st 1925

positive unintended consequence. The cognitive benefits are the main motivation for modern iodization campaigns (though goiter remains the most obvious sign of an iodine deficient population).

The pre-existing geographical variation in the prevalence of iodine deficiency, as measured by goiter rates in recruits, along with the timing of iodization, provide us with a nice natural experiment with which to look at the long-term impact of iodine deficiency eradication.

3.1 Evidence from mortality data

A second source for evidence on the spread of iodized salt comes from data on mortality from thyroid disease. Mortality data provides a good indicator of iodization because, as discussed above, the treatment designed to help goiter sufferers sometimes ended up killing them. The doctors and public health officials who worked for the introduction of iodized salt were aware of the potential danger of iodine-induced hyperthyroidism, but viewed the danger as minimal. In Europe, the potential negative side-effects of iodine treatment had been discussed as early as the nineteenth century [see McClure (1934) and Carpenter (2005)].

Figure 5 shows the annual rate of deaths in the US over the period 1910-1960 due to exophthalmic goiter, which accounted for the overwhelming majority of deaths due to thyroid disease over this period. Exophthalmic goiter is an enlargement of the thyroid accompanied by bulging of the eyes, which is sign of hyperthyroidism [18]. There is an extremely large rise in the death rate at the time of iodization: from 2.1 per 100,000 in 1923 to 2.7 in 1924, 3.4 in 1925, and 4.0 in 1926. Deaths remained elevated for at least a decade. There was also a large gender disparity. In 1926, the death rate was 1.1 per 100,000 for men 7.0 per 100,000 for women. The population of the United States in 1926 was 117 million, and so the rise of approximately two deaths per 100,000 people represented an extra 2,340 deaths in that year. Over the period 1925-1942 there appear to be at least 10,000 excess deaths that resulted from the introduction of iodized salt. We have found little discussion in the literature of what appears to be a high short-term price the country paid for long-run benefits resulting from this public health intervention (McClure 1934).

As would be predicted by the medical evidence that iodine-induced hyperthyroidism is most common among those with long-standing iodine deficiency, the rise in the death rate was highest, and persisted the longest, among older age groups.

[18] Source of data: XX. While some medical dictionaries use the definition stated here, others define exophthalmic goiter as being synonymous with Graves disease, which is the dominant cause of the condition today. It seems clear that the definition used in text was being applied in the vital statistics data.

Figure 5: US Deaths from exophthalmic goiter, 1920-1960

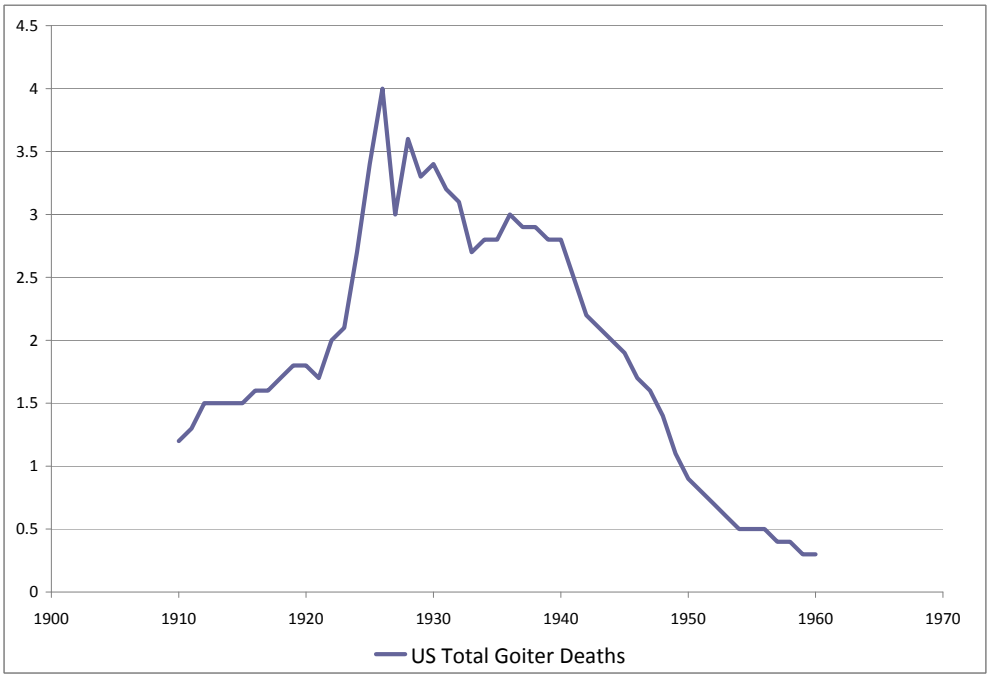


Figure 6: US goiter deaths by age group, 1921-1935

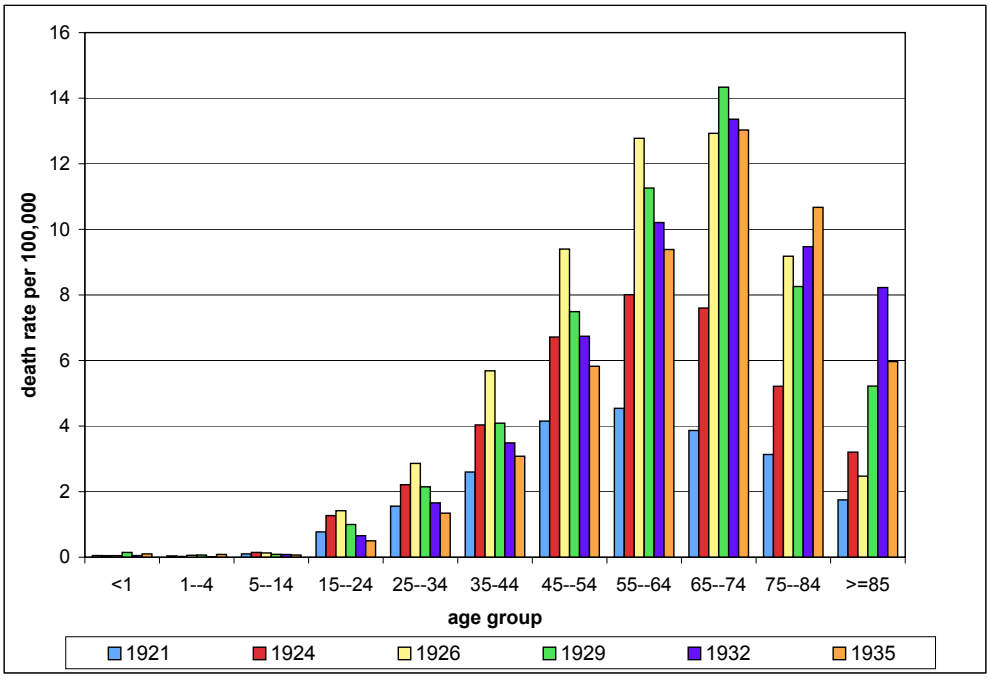


Figure 7: Changes in thyroid mortality vs. pre-existing goiter rates, 1921-1926

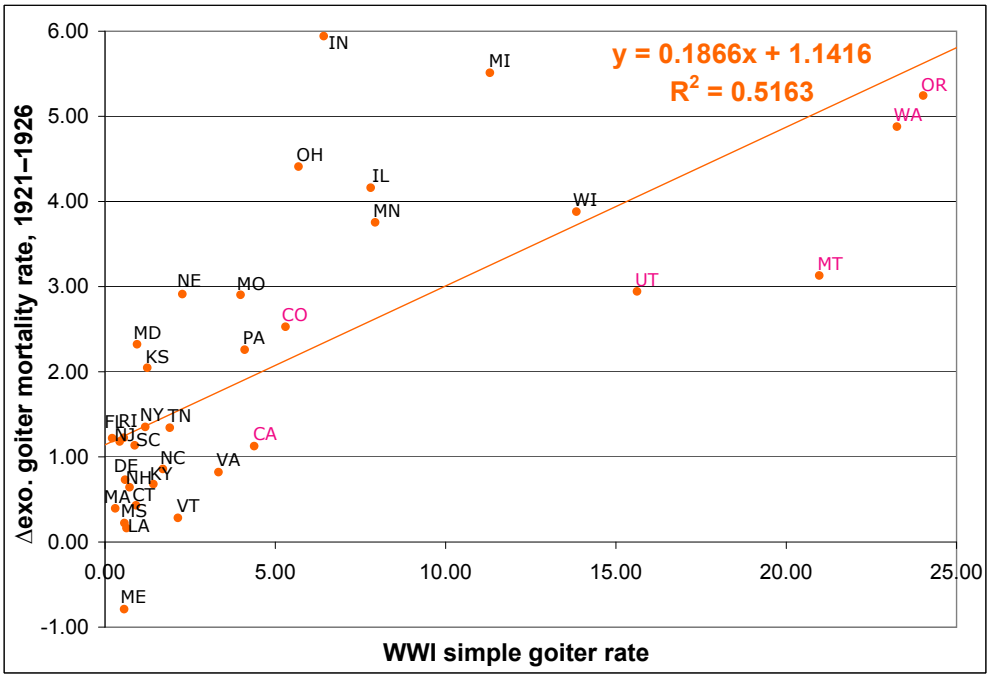
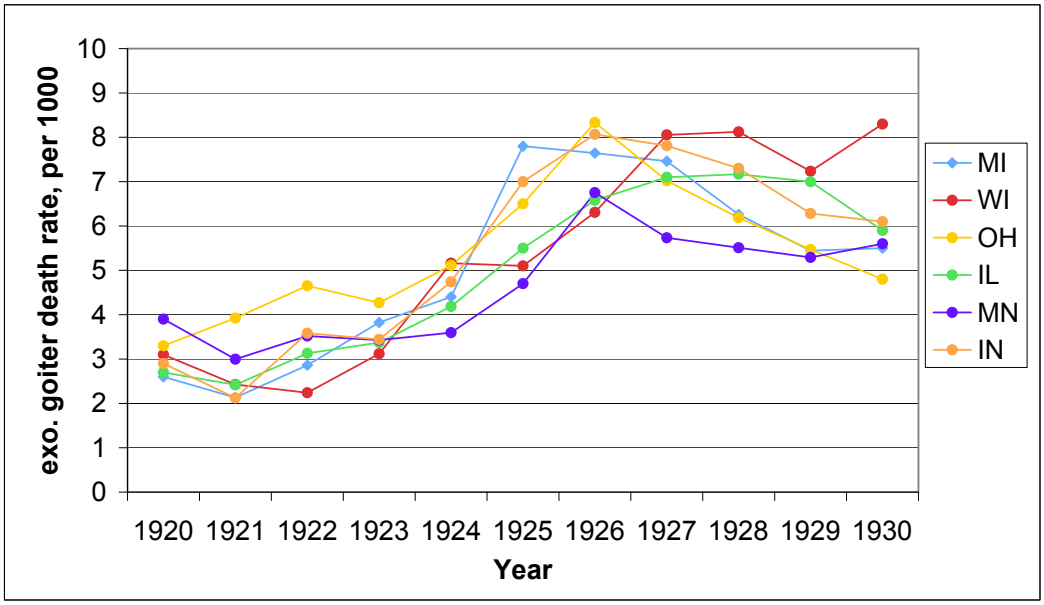
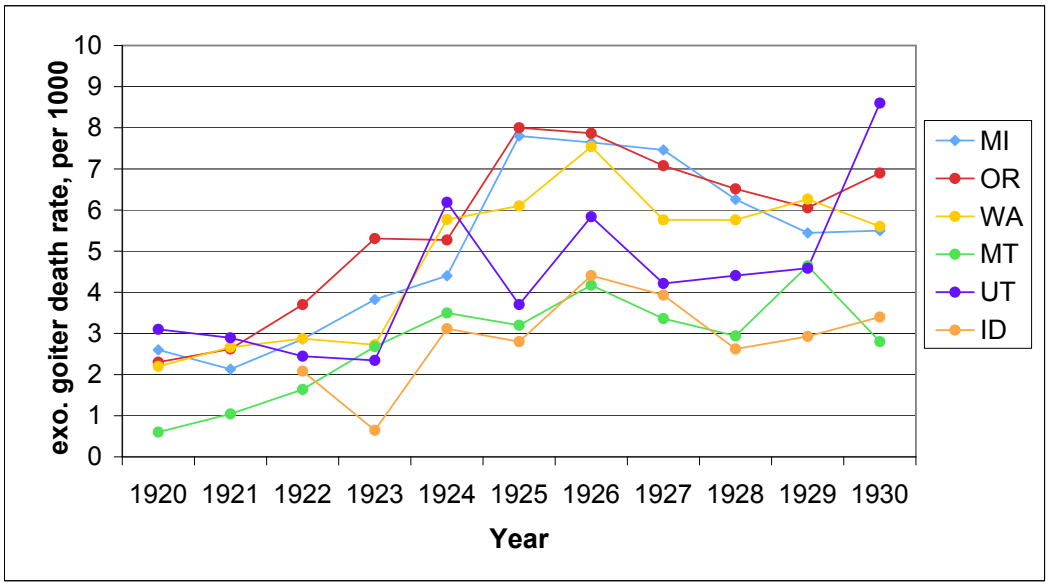


Figure 8: Deaths from exophthalmic goiter, Michigan and other states, 1920-1930





As figure 6 shows, deaths in the 25-34 age category less than doubled from 1921 to 1926, and had fallen below their 1921 level by 1935. In the 65-74 age category, deaths more than tripled between 1921 and 1926, and were still three times their 1921 level in 1935. The link between iodine deficiency and the rise in deaths at the time of iodization is also apparent looking across states. Figure 7 shows a scatter plot of rate of simple goiter among World War I recruits (from data discussed in the next section) and the change in the mortality rate from thyroid disease over the period 1921-26. Large increases in mortality all took place in states that had high levels of goiter due to iodine deficiency.

Given the strong evidence that it was salt iodization that caused the rise in thyroid disease deaths, we can use data on deaths to learn about the timing of iodization. We do not know the exact time lag between increased iodine consumption and death from thyroid disease in a susceptible person. However, we do know the timing of iodization in Michigan, so we can at least ask whether timing of deaths in that state looks similar to other high-goiter areas. Figure 8 shows annual data on thyroid disease death rates for Michigan along with the other 10 states in the upper right quadrant of Figure 7. For visual clarity, we divide the states into two groups, and in each picture we show data for Michigan for comparison. Compared to the other states in the upper Midwest, there is some evidence that Michigan may have experienced the surge in deaths earlier, but only by one year. Compared to the states in the mountains and Pacific west, there is no evidence of any lag compared to Michigan. Time series for these latter states are very jagged, however, because of their low populations.

4 Data Sources

We wish to examine the impact of the iodization of salt in 1924. In order to do so, we need two pieces of information. First, who was likely to benefit from salt iodization? Second, how did the outcomes of these individuals change after the iodization of salt in 1924?

As previously described, the presence or absence of endemic iodine deficiency depends on the iodine content of the soil and ground water. Individuals born in low iodine areas are much more likely to be iodine deficient than those born in high iodine areas. Iodizing salt will have a large effect on the former and no effect on the latter. The abrupt switch to iodized salt completes the natural experiment. Individuals born in high iodine areas should see no effect from salt iodization. Individuals born in low iodine areas, by contrast, should see effects whose size is related

to the severity of iodine deficiency before the treatment. The latter group provides our treatment group and the former group our control.

To implement this strategy we need data on the prevalence of iodine deficiency before 1924, as well as data on outcomes of individuals born in these areas both before and after 1924. Our primary data sources take advantage of two previously unused surveys of prime age American males in the early part of the twentieth century; we use data collected during the military drafts of World War I and World War II.

4.1 Defects in Drafted Men

For data on the prevalence of iodine deficiency before 1925 we use a volume entitled *Defects Found in Drafted Men*, published by the War Department in 1920 (Love and Davenport 1920)[19]. *Defects* summarizes the results of all the physical exams performed on draftees during World War I for both accepted and rejected men. Data on prevalence rates per 1000 are recorded for 269 different medical conditions. The data are regional, organized by units called draft sections. All but the lowest population states are broken down into multiple sections. Illinois and New York, for example are broken down into 8 sections. Each section is defined as a collection of counties[20]. In total, *Defects* has data on 151 separate regions of the country. Figure 9 is a map of the US showing the locations of sections from *Defects*.

The outcome of interest for our study is the rate of simple goiter, which is a direct result of iodine deficiency. Simple goiter is relatively common in the data, with a population weighted average prevalence of about 5 cases per 1000 and a median prevalence of 2.5 per 1000. The prevalence rates range as high as 29.85 cases per 1000. Though there are no sections with a zero rate of simple goiter, about one third of the sections have rates of less than 1 per 1000. Figure 10 shows the simple goiter rate at the state level. Rates range from a high of almost 27 per 1000 in Idaho to a low of 0.25 per 1000 in Florida.

The fact that the data are at a finer level of aggregation than the state level is important because there is significant regional variation within the high goiter states. For example, in the five sections in Michigan the rates reported in*Defects* range from over 25 in the Upper Peninsula to less than 10 in Detroit and the surrounding areas.

The incidences of iodine deficiency identified in *Defects* are almost certainly

[19]Many thanks to Hoyt Bleakley for making us aware of this marvelous book.

[20]Since county borders in the US are relatively static, it is straightforward to map the *Defects* sections to present day US counties.

Figure 9: Sections from *Defects Found in Drafted Men*

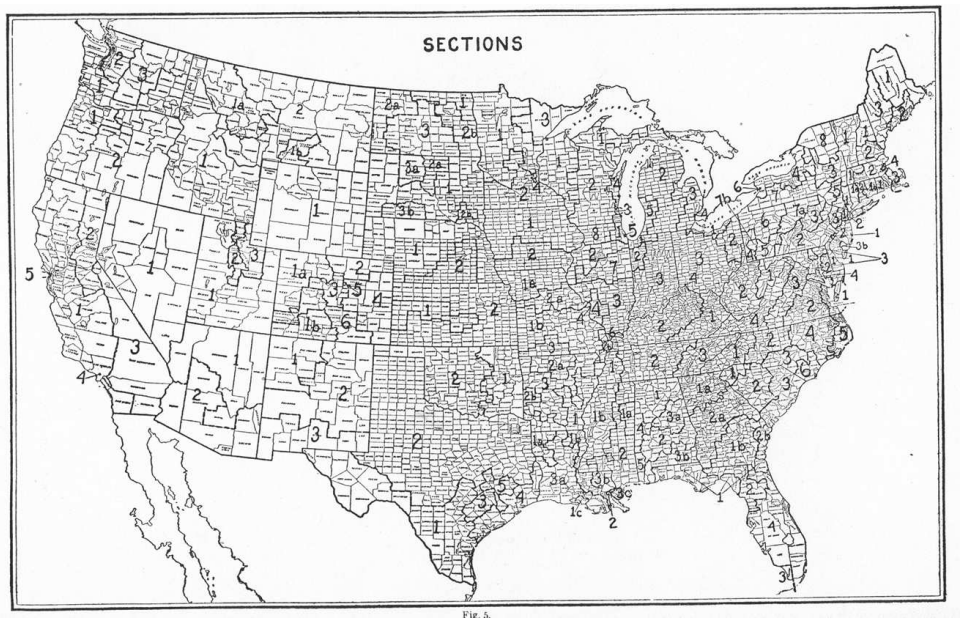


Figure 10: State level Simple Goiter Rates from *Defects Found in Drafted Men*

TABLE 18.—*Grand total for goiter, simple, with ratio per 1,000 men.*

State.	Number of cases.	Ratio per 1,000.	State.	Number of cases.	Ratio per 1,000.
Idaho	336	26.91	Kentucky	90	1.41
Oregon	421	26.31	District of Columbia	16	1.39
Washington	832	23.40	Kansas	48	1.25
Montana	576	21.00	Arizona	10	1.21
Utah	185	15.72	New York	308	1.19
Wyoming	102	15.37	Maryland	35	.94
Wisconsin	886	14.02	South Carolina	37	.94
Alaska	16	13.14	Connecticut	32	.89
Michigan	1,131	11.43	New Mexico	9	.88
North Dakota	156	8.73	Oklahoma	44	.72
Minnesota	578	8.04	New Hampshire	6	.70
West Virginia	307	7.89	Maine	13	.66
Illinois	1,397	7.79	Mississippi	24	.64
Iowa	458	6.68	Louisiana	32	.62
Indiana	464	6.49	Delaware	3	.59
Nevada	21	6.38	Alabama	29	.55
Ohio	798	5.59	Rhode Island	8	.55
Colorado	119	5.29	Georgia	33	.52
California	359	4.45	New Jersey	33	.43
Pennsylvania	829	4.10	Arkansas	17	.40
South Dakota	85	4.09	Massachusetts	29	.32
Missouri	342	3.99	Texas	36	.30
Virginia	188	3.38	Florida	6	.25
Nebraska	63	2.14	State not specified	186	1.96
Vermont	18	2.14			
Tennessee	120	1.96	Total	11,971	4.35
North Carolina	100	1.81			

Figure 11: Histogram of Section Level Simple Goiter Rates from *Defects Found in Drafted Men*

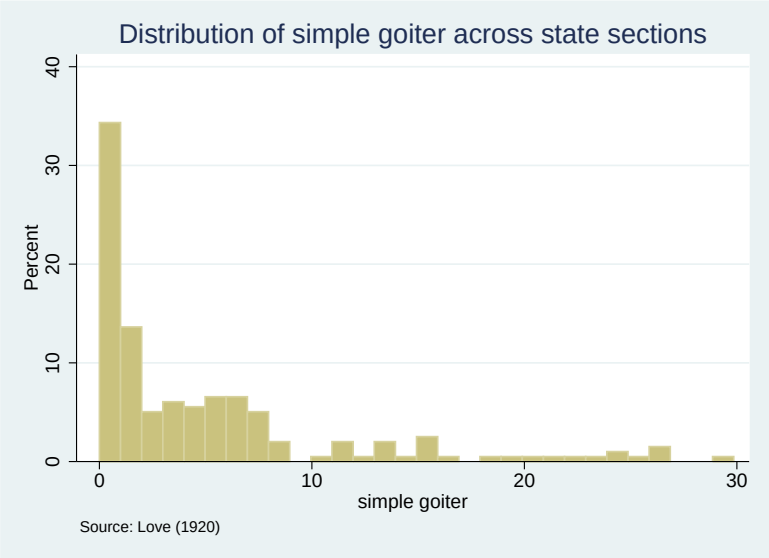
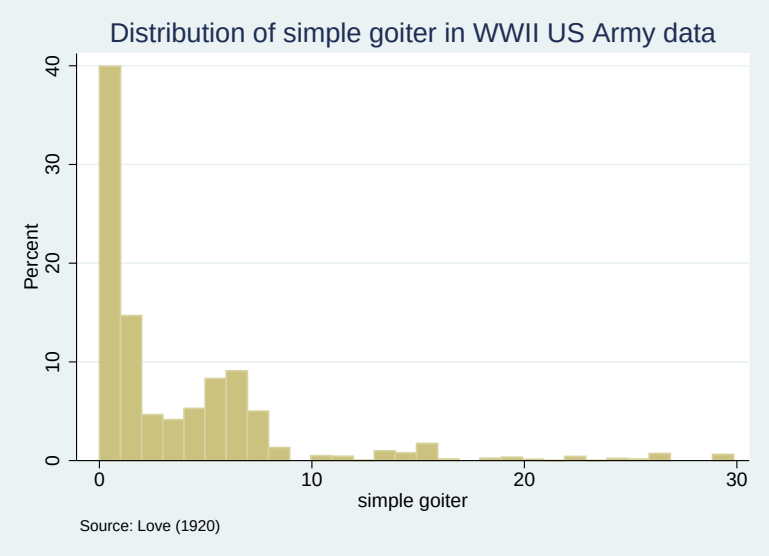


Figure 12: Histogram of Population Goiter Rates from *Defects Found in Drafted Men*



geographic in origin. In a paper published in the Journal of the American Medical Association in 1924, J.F. McClendon[21] and Joseph C. Hathaway provided measures of the iodine content of drinking water from 69 localities across the US[22]. These measures came from lakes, springs, rivers and wells. Their paper includes US maps with the low-iodine areas being shaded, and other maps where the high-goiter areas are shaded (their data on goiter come from the *Defects* Book). The two shaded areas in the two maps largely overlap (McClendon 1924). The data on the iodine content of water are not plentiful enough to be used as alternative measures of iodine deficiency, in addition to the goiter data that we have. They are useful, however, because the negative correlation between the iodine content measures and the goiter in their section of origin suggests that goiter variation was due to geographical factors. Figure 13 is a scatterplot relating the log of iodine to the level of simple goiter in the section where the origin of the water sample belongs (typically a town). The corresponding regression line is:

$$\begin{array}{rcl} \text{simple goiter} & = & 10.854 - 1.422 \times \log \text{ iodine} \\ & & (1.445) \quad (0.355) \end{array}$$

(Standard errors in parentheses, N=67)

We expect that the effect of iodizing salt will be larger in areas where the prevalence of goiter in *Defects* is highest. Since the medical literature suggests that the largest impact of iodine deficiency is in utero, we would like to identify individuals born in high and low goiter areas both before and after 1924. Luckily for our purposes, the United States government performed a survey of this population during the draft for World War II.

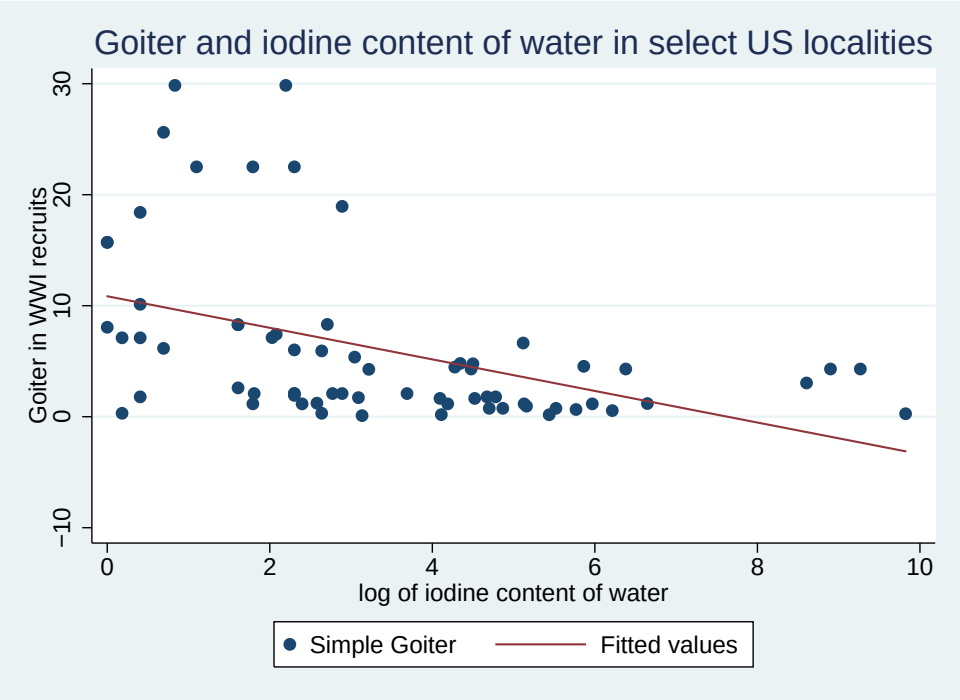
4.2 World War II Enlistment Data

The World War II enlistment data are from the National Archives and Records Administration (NARA). The data has its origin in punch cards produced during the enlistment process for the United States Army, including the Women's Army Auxiliary Corps. It includes both volunteers and draftees. After the war these punch cards were converted to microfilm. In 1994 NARA hired the census department to scan the microfilm into a collection of over 9 million enlistment records from 1938-1946. Though not complete, these records represent the majority of the enlistment into the Army during this period. Of the 1,586 rolls of microfilm, 1,374 (87%) were successfully scanned, leaving approximately 1.5 million punch cards unrecorded.

[21] Professor of Physiologic Chemistry at the University of Minnesota Medical School.

[22] Parts of Iodine per hundred billion parts of drinking water.

Figure 13: McClendon's data on the iodine content of water



source: McClendon (1924)

The missing rolls are not sequential, and there are no indications that the records are missing in any systematic fashion. In addition to the missing rolls, several hundred thousand individual records were unreadable.

Though the format of the punch cards changed somewhat over the course of the war, the coding for basic demographic information was consistent. The demographic fields are name, serial number, state and county of residence, place and date of enlistment, place and year of birth, race, education, and marital status. In addition, the particular branch of the Army that the enlistee entered is coded. One can also infer through the serial number whether the person was drafted. There are no records for individuals who entered the Navy or Marines.

The sample we have available to us is obviously very large and the timing of the draft is nearly perfect for our purposes. Limiting our sample to white men, we have data on over 300,000 from each birth year between 1921 and 1927, giving us extremely complete coverage on both sides of the 1924 salt iodization date. Unfortunately, the data do not include the county of birth, only the state. We therefore limit our sample to individuals whose birth state is identical to their state of residence and we assume that the county of residence upon enlistment is the county of birth. This reduces the sample by less than half, leaving us with almost 2 million records of individuals born between 1921 and 1927.

4.3 Test Scores

All enlistees were given the Army General Classification Test (AGCT), a predecessor to the AFQT that is currently given to enlistees. This test score would be an ideal outcome for our study, since the primary effect of iodine deficiency in utero is reduced cognitive ability. Unfortunately, the score is not recorded in the data that we have available(with one notable exception, discussed below). We can, however, make some crude inferences about the test scores by examining which army branch the enlistees were assigned to.

Each test taker was assigned a grade of I, II, III, IV, or V, with class I being the highest score on the test and V the lowest. Jobs within the Army were deemed to require soldiers from different groups. For example, skilled positions like mechanics tended to get class I or II enlistees, while lower skill jobs, like cooks tended to get class IV or V enlistees. We do not know the particular job assignment of each recruit. However, we can identify enlistees who were assigned to the Army Air Forces (AAF) versus those who were assigned to the Army Ground Forces (AGF). Roughly 14% of all enlistees were assigned to the AAF over the course of the war, though this proportion varied from year to year. The year to year variation is

Table 1: Percent of enlistees assigned to the Army Air Forces by year.

Year	Percentage in Air Corps
1940	13.7
1941	32.6
1942	18.8
1943	03.8
1944	10.8
1945	13.9
1946	19.1
Total	14.0

described in Table 1[23].

Table 2 is a summary of our enlistment data. It gives the total sample size and the percentage of recruits going to the Airforce for each cohort and each enlistment semester. The number of enlisted men started increasing in 1942, and it peaked in the second semester of that year, as well as the first semester of 1943. People born after iodization enlisted in large numbers starting the first semester of 1943. The proportion of recruits going to the Airforce was particularly low in 1943.

[23]The year to year variation is largely driven by changes in US participation in the war. In 1941, the US was largely engaged in the Air War and had less need for ground forces. By 1943 the need for ground forces rose considerably.

Table 2: Sample size and probability of joining the AAF by birth year and enlistment semester

semester of enlistment	Year of Birth 20	21	22	23	24	25	26	27	28	Total	
40.1	43	65	32	10						**150**	**Sample size**
	0.19	0.12	0.09	0.00						**0.13**	**% going to AAF**
40.2	24,849	28,448	20,704	66						**74,067**	**Sample size**
	0.15	0.13	0.14	0.08						**0.14**	**% going to AAF**
41.1	19,864	17,851	15,617	3,086	15					**56,433**	**Sample size**
	0.19	0.16	0.20	0.36	0.00					**0.19**	**% going to AAF**
41.2	34,252	6,732	6,243	6,604	6					**53,837**	**Sample size**
	0.38	0.68	0.61	0.57	0.50					**0.46**	**% going to AAF**
42.1	74,192	33,054	12,145	10,276	2,897	85				**132,649**	**Sample size**
	0.16	0.33	0.45	0.40	0.30	0.21				**0.25**	**% going to AAF**
42.2	107,383	185,140	151,019	44,984	29,751	104				**518,381**	**Sample size**
	0.07	0.07	0.16	0.59	0.60	0.22				**0.17**	**% going to AAF**
43.1	20,338	23,146	60,682	155,601	144,109	29,310	96			**433,282**	**Sample size**
	0.06	0.09	0.04	0.02	0.01	0.02	0.09			**0.02**	**% going to AAF**
43.2	10,761	10,681	10,449	15,281	28,303	71,648	66			**147,189**	**Sample size**
	0.07	0.08	0.08	0.06	0.04	0.09	0.32			**0.08**	**% going to AAF**
44.1	14,817	11,180	9,397	9,711	11,099	41,627	30,354	14		**128,199**	**Sample size**
	0.04	0.06	0.06	0.05	0.04	0.18	0.26	0.14		**0.14**	**% going to AAF**
44.2	11,559	9,163	7,019	8,824	11,071	16,005	76,846	27		**140,514**	**Sample size**
	0.01	0.02	0.02	0.01	0.00	0.01	0.13	0.00		**0.08**	**% going to AAF**
45.1	4,803	4,313	4,081	5,022	6,791	8,318	56,995	30,342	55	**120,720**	**Sample size**
	0.01	0.01	0.01	0.00	0.00	0.00	0.20	0.07	0.09	**0.11**	**% going to AAF**
45.2	8,855	9,751	9,467	10,947	13,280	16,014	41,103	82,226	9,738	**201,381**	**Sample size**
	0.28	0.26	0.22	0.19	0.15	0.11	0.11	0.12	0.37	**0.15**	**% going to AAF**
46.1	5,405	6,694	6,811	7,762	9,426	11,572	19,540	80,613	66,660	**214,483**	**Sample size**
	0.37	0.33	0.30	0.25	0.19	0.14	0.12	0.11	0.27	**0.19**	**% going to AAF**
46.2	1,946	2,143	2,438	2,609	3,292	3,809	5,252	20,767	50,859	**93,115**	**Sample size**
	0.41	0.40	0.39	0.37	0.31	0.22	0.17	0.10	0.19	**0.19**	**% going to AAF**
Total	**339,067**	**348,361**	**316,104**	**280,783**	**260,040**	**198,492**	**230,252**	**213,989**	**127,312**	**2314400**	**Sample size**
	0.14	**0.12**	**0.16**	**0.16**	**0.10**	**0.10**	**0.16**	**0.11**	**0.25**	**0.14**	**% going to AAF**

These AAF enlistees were systematically different than other enlistees during the war. There is ample evidence that the AAF enjoyed preferential assignment of inductees compared to other Army branches[24].

4.4 The Battle for the Best Enlistees

The Army Air Forces (AAF), which was still part of the Army during World War II, had a large proportion of jobs that required skilled recruits relative to the Army Ground Forces (AGF). Throughout the war, the AAF pushed to have a large proportion of the more highly skilled recruits assigned to the Air Forces. In February 1942, the AAF successfully got the 75 percent rule put into place. Under this rule, 75 percent of the men assigned to the AAF were to have scored above 100 (the median score) on the AGCT[25]. From this, we can infer that individuals assigned to the AAF during this period have, on average, higher test scores than those assigned to the AGF. Because the AGCT is a normalized exam, we can even infer how much higher this average was.

Unsurprisingly, the AGF was not pleased and this rule was not in place for the entire war. Though lower skilled recruits could easily be used in the infantry, the AGF was concerned about having a supply of recruits who could become high-quality combat leaders. The AGF successfully lobbied the War Department to change the rule on August 1, 1942 so that the proportion of above average men received by the AAF was reduced to 55 percent[26].

The AAF fought back against this change by using a second test, the mechanical aptitude (MA) test, as a screen for AAF recruits. At first, they simply requested that a higher proportion of men assigned scored above average on the MA test. This was later formalized. From December 1942 until June 1943, the AAF was supposed to be assigned 55 percent of their new recruits from the group with scores greater than the mean on both the AGCT and the MA tests. Combining the two tests was obviously more restrictive than just using one test. In fact only 37.5 percent of all recruits were above average on both tests[27]. This rule was allowed to expire, but it is clear that the AAF continued to get higher quality of recruits even after the rule formally expired. For example, for those inducted in 1943, 41.3% of soldiers assigned to AAF were class I or II. This percentage is higher than the one corresponding to Ground Combat Arms (29.7%) and Services (36.5%) [data come from Palmer et al.

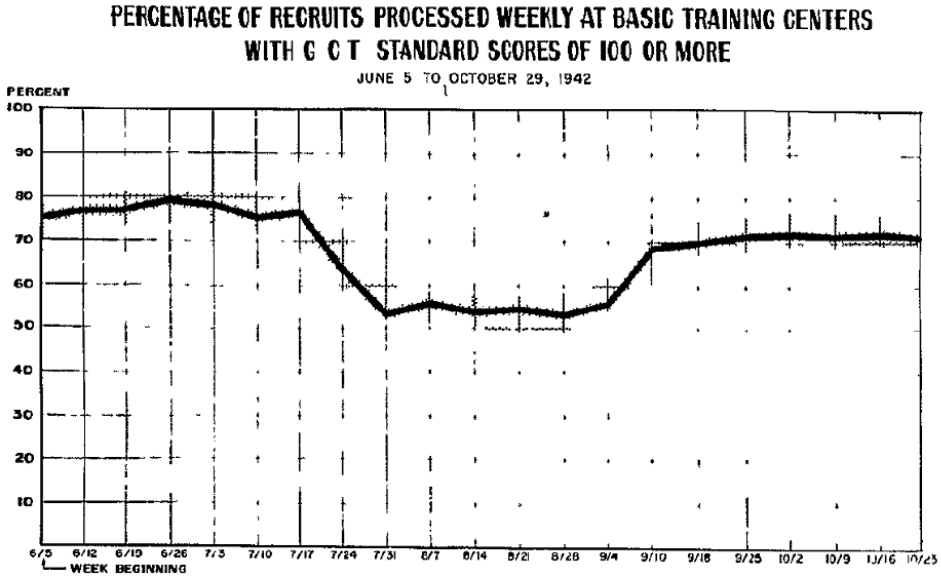
[24] See, for example, Palmer, Wiley and Keast (1948, p.21)

[25] US Air Force Historical Study #76, Classification and Assignment of Enlisted Men in the Air Arm 1917-1945, p. 44.

[26] ibid, p.46.

[27] ibid, p.56.

Figure 14: Percentage of Air Corps Recruits with above average AGCT scores



source: US Air Force Historical Study #76, Classification and Assignment of Enlisted Men in the Air Arm 1917-1945.

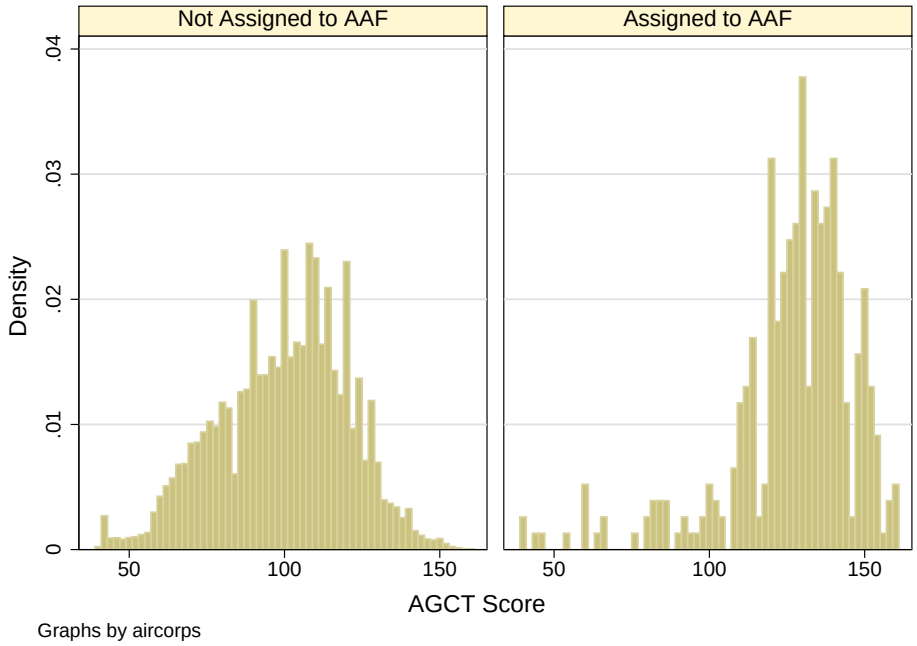
(1948)].

Figure 14 is a graph from the War Department showing the percentage of recruits assigned to the AAF with above average AGCT scores during the period of time that these rule changes were occurring. During the early part of the graph, the 75 percent rule was clearly in operation. At the end of July, the abolition of the 75 percent rule can be seen, with the AAF only getting 55 percent of recruits from the above average group. By September, the AAF had managed to return to the old proportions via the 55 percent mandate on both the AGCT and MA tests.

Additional evidence on the positive selection of men with high cognitive function into the AAF comes from an anomaly in the WWII enlistment data. As mentioned above, all new enlistees in the army took the AGCT test, but this test result was not generally recorded on the punch cards that are the primary source for the enlistment data. However, for the the three months March-May, 1943, AGCT scores were recorded in the fields marked weight for almost all recruits. [28] The fact that AGCT was coded in this field for some subset of the war is suggested in the documentation. Observing the actual distribution of values in the weight field confirms this is true for a subset of observations. Examining observations from enlistments through 1942,

[28] We are grateful to Joseph Ferrie for making us aware of this data.

Figure 15: AGCT Scores for AAF versus all enlistees



source: WWII enlistment records.

the weight field has a mean of 150 and a standard deviation of 22. For the period of March through May of 1943, the mean is roughly 100 and the standard deviation it about 20, consistent with normalized AGCT scores.

Figure 15 shows a histogram of AGCT scores for recruits entering the Air Corps alongside a histogram for all other recruits.[29] For the non Air Corps group there are 422,516 reported scores with a mean of 99.4 and a standard deviation of 20.7. This distribution matches the normed distribution of the AGCT (which were supposed to be mean of 100 and standard deviation of 20). The second panel shows the histogram of recruits entering the AAF in this period. The mean (126.5) suggests that the AAF was, at this point, receiving substantially better recruits than the ground forces. However, as seen in Table 2, this was also a period in which very few recruits were entering the AAF – this histogram is based on only 384 recruits.

[29]Because the recording of AGCT scores in this field was for such a short period of time there is some question as to whether all enlistment places coded this field the same way. For this reason the histograms are drawn using only data from enlistment places with over 500 recruits and where the mean of the weight field is between 80 and 120 within the enlistment place. This eliminates less than 11,000 observations and does not substantially change the distributions.

The preferential treatment of the AAF lasted until the end of 1943, when the Infantry crisis broke out. The need for high-quality ground forces grew more acute in 1944 and lasted until the end of the War, while, at same time, air operations were not as important as in previous years. This meant that priorities between the AAF and the AGF reversed in favor of the latter, and the Army classification system was revised to allow for better-quality soldiers to join the Ground Forces[30]. With this classification procedure, as well as with tranfers within the Army commands, the AGF had an influx of high-quality men, especially in the end of 1944 and afterwards, as opposed to the Air Force. At the same time, the distribution of recruits among the Army commands changed, and most of the new inductees were assigned to the Ground Forces.

Through our enlistment records we know whether or not an individual was assigned to the AAF or the AGF. We know that individuals assigned to the AAF have higher test scores than the average enlistee for the initial phase of the war. We can also see the selection into the AAF over the course of the war by looking at the proportion of high school grads assigned to each branch. Table 3 and Figure 16 give the proportion of high school graduates in each branch by birth year. Figure 17 shows the proportion of high-school graduates by enlistment month, separately for the Airforce and the rest of the Army.

As expected, Table 3 and Figure 16show that the younger cohorts were less likely to have a high-school degree than the older cohorts. It is also clear that there was positive selection into the Airforce, which became less and less pronounced over the course of the war. By the time the 1927 and 1928 cohorts enlisted, the Ground Forces were getting equally, if not better-qualified recruits than the Air Forces. Figure 17 shows the downward trend in the proportion of AAF recruits who had high-school diplomas, which becomes steeper towards the end of 1943, when the Infantry crisis broke out and priority was given to the Ground Forces. We can also see from Figure 17 the spike in the proportion of high-school graduates in the Air Force around February 1942, when the 75% rule was put into effect. Also, Figure 17 shows the temporary decrease in quality of AAF recruits in the second half of 1942, when the 75% rule was withdrawn. In late 1942 and early 1943, when the Mechanical Aptitude Test was put into use, the Air Force returned to the preferential-treatment status it enjoyed before.

It is clear that the Air Corps selected higher quality enlistees for the cohorts

[30]The New classification procedure was based on "The Physical Profile System", which became operative in 1944, and classified recruits into three profiles, according to their ability to withstand strenuous combat conditions. 80% of men assigned to the AGF had to belong to the top profile, whereas only 10% of the AAF recruits came from the top group.

Table 3: Percent of high school graduates by birth year and branch.

	HS Graduation Rate		
Birth Year	Air Corps	Ground Forces	Total
1920	76.0	42.8	47.5
1921	75.9	41.3	45.6
1922	70.1	39.7	44.5
1923	60.5	43.6	46.3
1924	52.1	39.4	40.7
1925	56.7	35.9	37.9
1926	50.9	36.7	39.0
1927	33.3	38.4	37.9
1928	26.3	40.5	37.0
Total	59.1	40.1	42.8

Figure 16: High-School Graduation Rates by birth year

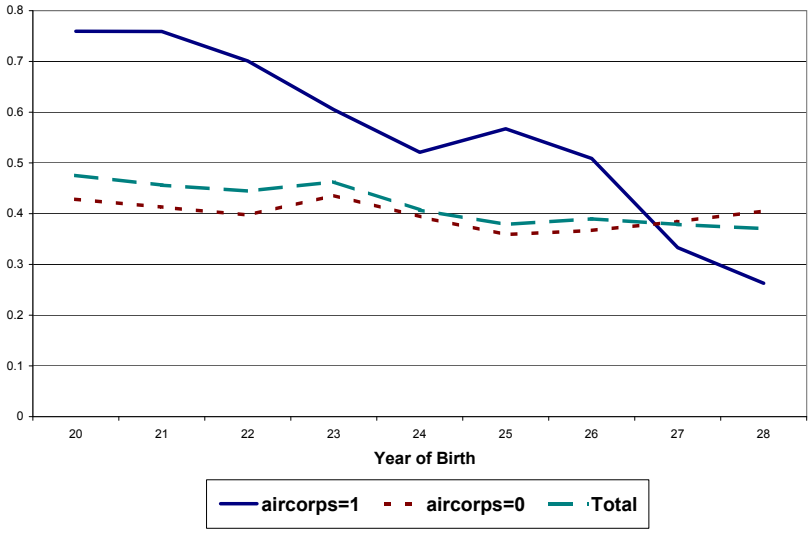
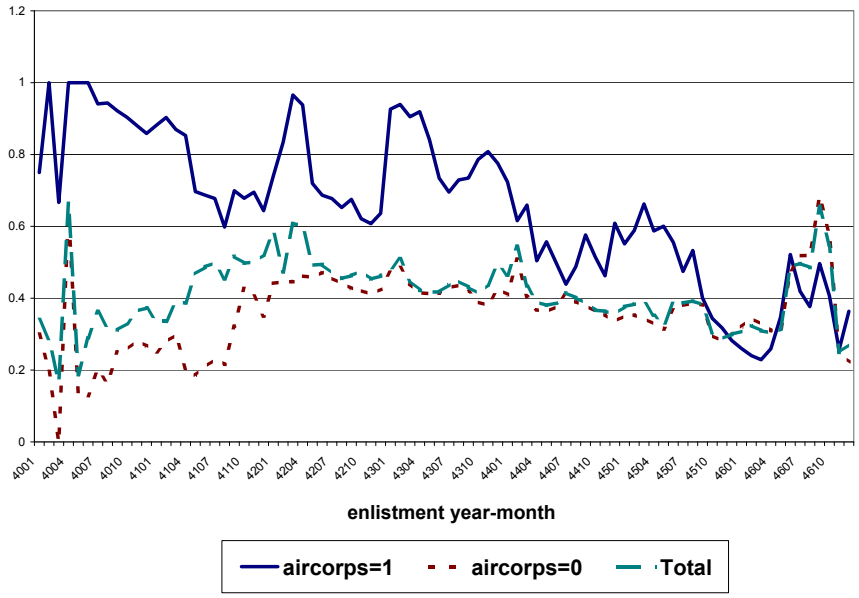


Figure 17: High-School Graduation Rates by enlistment month



born from 1920 until 1926. Luckily, this gives us good coverage of pre and post treatment enlistees. As will be seen below, the fact that the for the 1927 and 1928 birth cohorts there was *not* positive selection into the Air Corps is also consistent with our empirical results.

We will take advantage of the selection of enlistees into the Air Corps in two ways. First, if iodine deficiency affects cognitive ability we should expect a jump in the relative rate of assignment to the AAF after 1924 in those counties where goiter rates were high in the Defects data. Second, by exploiting the normal distribution of the AGCT test, and the joint distribution of the AGCT and MA tests, we can infer the average test scores of individual assigned to the AAF versus those assigned to the AGF under each of the assignment regimes. We can then assign to each of the individuals in our data set a test score based on their assignment and date of enlistment[31].

5 Identification

Our identification strategy relies on two important sources of variation. First, the impact of the intervention is a function of the size of the problem in the treated populations. In regions where goiter was low among men drafted in WWI, we expect little change after iodizing salt. In regions where goiter was high we expect to see a significant increase in the proportion of men being assigned to the Army Air Forces after iodizing salt. Second, the rapid introduction of the iodized salt provides for a clean distinction between the treated and the untreated. We expect to see a sharp difference between the years before 1924 and the years after. High goiter areas therefore provide the treatment group and low goiter areas the control group. Years before 1924 are pre-treatment and years after 1924 are post-treatment.

The basic regression specification is:

$$y_i = \alpha + \sum_{t \neq 1924} \beta_t [goiter \times I(t = birthyear)] + Controls + \epsilon \qquad (1)$$

where y_i is one of two outcome variables measured at the individual level. First, y_i is a dummy variable coded one if the individual entered the AAF and zero if they did not. Second, y_i is the implied AGCT score assigned to each individual based on the value of the AAF dummy and their induction date.

The goiter rate interacted with a set of birth year dummies provides the main coefficients of interest. The year iodized salt was introduced, 1924, is the excluded

[31] See Appendix A for the details of these calculations.

category. The pattern of coefficients on this set of dummies will show how the relationship between the geologically determined level of iodine deficiency (as measured by goiter rates in WWI enlistees) and cognitive ability (as measured by the likelihood of entering the AAF) changes over time. The iodization of salt in 1924 should make these coefficients significantly larger (less negative) in the later years.

In all the regressions we include a number of additional controls. We include a full set of section dummies. We also sometimes include a goiter x year term to control for nutritional trends that may have been reducing the impact of low iodine soil over time. Since the proportion of enlistees being assigned to the AAF varies dramatically over the course of the war, we include a full set of birth year dummies x enlistment year dummies in one specification. This will also control for any systematic relationship between birth year, enlistment year and the propensity to enter the AAF which is shared across all members of the cohort. This implicitly provides a control for enlistment age. In another specification, instead of including birth year dummies interacted with enlistment year dummies, we include birth year dummies and enlistment month dummies separately[32]. Results are consistent across specifications.

Since we have many observations utilizing a single section level data point for the goiter level we cluster our standard errors at the *Defects* section level.

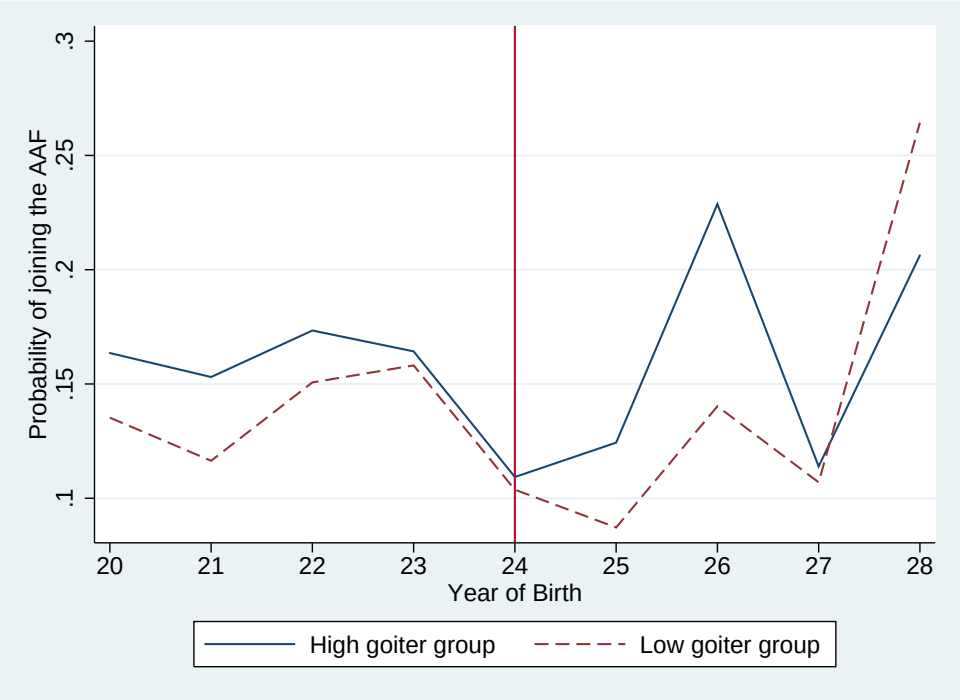
6 Results

Figure 18 is a basic, "first-cut" graphical preview of our results. We plot the probability of joining the Airforce for each cohort of recruits, by high-goiter and low-goiter group, according to the goiter level in their section of birth. The high goiter group contains *Defects* sections which are at the top 25% of the distribution with a cutoff of 5.4 goiter cases per 1000. From Figure 18 we see the jump in the probability of joining the Airforce for the 1925 cohort coming from a high-goiter area, relative to the same cohort coming from a low-goiter area. The jump is even more pronounced for the 1926 cohort. This is reasonable, if we assume that iodized salt caught up in the market with some lag. Note that the 1927 and 1928 cohorts only enlisted after the AAF stopped receiving preferential treatment among Army commands.

A better graphical representation of our results is given by Figure 19. Figure 19 plots the average residuals for each cohort - goiter group combination, after running an OLS regression of an Airforce dummy on enlistment month dummies (for each

[32]For this specification, we only use those recruits who enlisted from July 1940 to December 1946, because there were very few men who enlisted in the period January-June 1940.

Figure 18: Probability of joining the Airforce



birth year separately, so we ran 9 regressions for this graph). Figure 19 tells the same story as Figure 18, but it's more convincing, because it accounts for the effect of enlisting in any particular month over the course of the war. Figure 19 shows clearly that for the cohorts born after iodization in a previously high-goiter area, and enlisting when there was positive selection into the Airforce, there was a jump in their probability of joining the Airforce, as opposed to those coming from low-goiter areas. One can go as far as saying that Figure 19 also shows the *negative* selection into the Airforce for the 1928 cohort, who enlisted during the final phase of the war.

6.1 Linear Probability Model of joining the AAF

Table 4 displays results estimated as a linear probability model using OLS. The dependent variable is a dummy indicating whether the individual entered the Army Air Forces (AAF). The main regressors are the level of goiter in the region where the recruit was born interacted with birth year dummies. The excluded year is 1924, the year that iodized salt was introduced. In the first two columns of the table we include goiter trend (defined as the section goiter rate interacted with year of birth)

Table 4: Air Force dummy against initial goiter level interacted with birth year dummies

	(1) Air Force dummy	(2) Air Force dummy	(3) Air Force dummy	(4) Air Force dummy
goiter X birthyear20			0.00132	0.00081
			(0.00069)	(0.00121)
goiter X birthyear21	0.00101	0.00146	0.002	0.00207
	(0.00040)*	(0.00045)**	(0.00067)**	(0.00106)
goiter X birthyear22	0.00058	0.0007	0.00124	0.00111
	(0.00067)	(0.00067)	(0.00079)	(0.00102)
goiter X birthyear23	-0.00057	-0.00085	-0.00024	-0.00065
	(0.00033)	(0.00048)	(0.00026)	(0.00034)
goiter X birthyear25	0.00378	0.00323	0.00345	0.00303
	(0.00110)**	(0.00088)**	(0.00110)**	(0.00084)**
goiter X birthyear26	0.00593	0.00533	0.00527	0.00493
	(0.00229)*	(0.00168)**	(0.00227)*	(0.00187)**
goiter X birthyear27	0.0012	0.00041	0.00021	-0.0002
	(0.00100)	(0.00122)	(0.00084)	(0.00068)
goiter X birthyear28	-0.00299	-0.00363	-0.00432	-0.00444
	(0.00190)	(0.00266)	(0.00162)**	(0.00183)*
goiter X year of birth	-0.00033	-0.0002		
	(0.00017)	(0.00030)		
Constant	0.08622	0.64526	0.05618	0.62685
	(0.04280)*	(0.03220)**	(0.03680)	(0.02576)**
Birth year X Enlistment Year Dummies	YES	NO	YES	NO
Birth year dummies	NO	YES	NO	YES
Enlistment month dummies	NO	YES	NO	YES
Section dummies	YES	YES	YES	YES
Observations	2,275,622	2,274,698	2,275,622	2,274,698
R-squared	0.13	0.13	0.13	0.13

* significant at 5%; ** significant at 1%

All regressions clustered at the state-section level

Regressions (1) and (3) - white men enlisted in the period 1940-1946

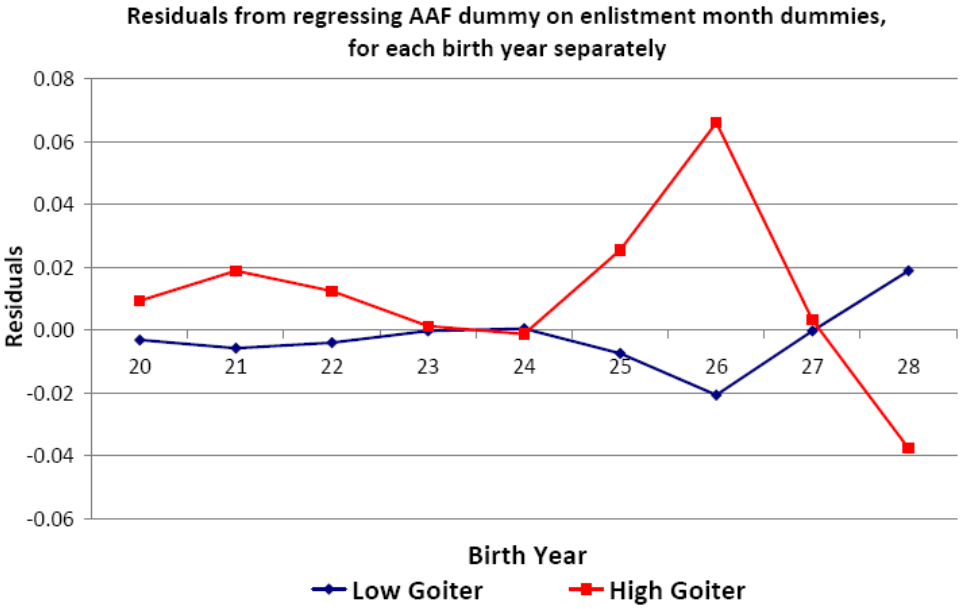
Regressions (2) and (4) - white men enlisted in the period July 1940- December 1946

Table 5: Air Force dummy against high goiter dummy interacted with birth year dummies

	(1) Air Force dummy	(2) Air Force dummy	(3) Air Force dummy	(4) Air Force dummy
highgoiter X birthyear20	0	-0.0853	0.0067	-0.00908
	[0.00000]	[0.05016]	[0.01187]	[0.02315]
highgoiter X birthyear21	0.01991	-0.03943	0.02493	0.01772
	[0.00761]**	[0.03582]	[0.01076]*	[0.01773]
highgoiter X birthyear22	0.01346	-0.0286	0.01681	0.00951
	[0.01227]	[0.02288]	[0.01260]	[0.01479]
highgoiter X birthyear23	-0.00557	-0.02347	-0.0039	-0.00441
	[0.00415]	[0.00782]**	[0.00291]	[0.00414]
highgoiter X birthyear25	0.04065	0.04637	0.03897	0.02731
	[0.01381]**	[0.01389]**	[0.01500]*	[0.00934]**
highgoiter X birthyear26	0.08746	0.11092	0.08411	0.07281
	[0.02332]**	[0.03195]**	[0.02618]**	[0.01964]**
highgoiter X birthyear27	0.01854	0.05782	0.01351	0.00066
	[0.01140]	[0.02018]**	[0.00992]	[0.00861]
highgoiter X birthyear28	-0.06017		-0.06687	-0.07621
	[0.03161]		[0.02490]**	[0.03106]*
highgoiter X year of birth	-0.00168	-0.01905		
	[0.00297]	[0.00776]*		
Constant	0.0635	0.73807	0.05373	0.62699
	[0.04598]	[0.05636]**	[0.03712]	[0.02578]**
birth year X enlistyear dummies	YES	NO	YES	NO
birth year dummies	NO	YES	NO	YES
enlist month dummies	NO	YES	NO	YES
Observations	2275622	2274698	2275622	2274698
R-squared	0.13	0.13	0.13	0.13

* significant at 5%; ** significant at 1%
All regressions include state-section level dummies
All regressions clustered at the state-section level
Regressions (1) and (3) - white men enlisted in the period 1940-1946
Regressions (2) and (4) - white men enlisted in the period July 1940- December 1946

Figure 19: Graph with Residuals



Note: Graph represents residuals from regressing AAF dummy on enlistment month dummies for each year separately, and then taking avg residual for each birth year, by goiter group

to control for any secular trends in the incidence of goiter.

There is a clear break before and after the excluded year 1924. The coefficients for 1922 and 1923 are small and insignificant. The coefficients on 1925 and 1926 are positive and highly significant. The fact that the coefficient rises from 1925 to 1926 is consistent with there being some lag in the diffusion of iodized salt. The later years, 1927 and 1928 are not significantly different from zero when the trend is accounted for, although 1928 is negative and significant when the trend is not included. However, as Table 3 shows, in 1927 and 1928 the selection appears to be pushing lower quality recruits toward the AAF, not higher, so we are not surprised that these years do not match the 1925 and 1926 coefficients.

The effects are large in high goiter areas. The coefficients on 1925 and 1926 are between 0.003 and 0.005. The highest goiter areas have levels of roughly 30 per 1000 cases. Multiplying the coefficients times 30 indicates that the highest goiter areas saw a 9-15 percentage point increase in the likelihood of joining the AAF if they were born after 1924.

In Table 5 we separate the sample into high and low goiter sections. The high goiter areas are those in the top 25% of the distribution with a cutoff of 5.4 goiter cases per 1000. The main regressors are the high goiter dummies interacted with

birth year dummies.

The results echo the earlier results. Individuals from high goiter areas see a 3-11% increase in the probability that they enter the Air Corps after the iodization of salt in 1924. Once again, the effect is bigger for 1926 than for 1925. Given that the average rate of assignment to the Air Corps was roughly 14% for the entire sample, this represents a large effect.

6.2 Logit results

We also ran logit models of the probability of joining the AAF, using the same right-hand-side variables as in the linear probability model of the previous section. Logit results are displayed in Tables 6 and 7. Table 6 lists results of the interaction of goiter in the *Defects* section of origin and birth year dummies, whereas Table 7 lists results of the interaction of birth year dummies and a dummy variable for belonging to a high-goiter group. Regardless of the exact specification, we always see a jump in the coefficients for those cohorts born in 1925 and 1926, after salt iodization.

Table 8 lists the marginal probabilities from the logit specifications where the sample is separated in high- and low- goiter areas. The marginal probabilities are very similar to those derived with the linear probability model. Recruits born in 1925 or 1926 in previously high-goiter areas are 3-11 percentage points more likely to join the Airforce.

6.3 Falsification exercise with other diseases

As a falsification exercise we ran regressions using data on 58 defects other than goiter, which were also reported in *Defects*. For each defect, we computed the same linear probability model of joining the airforce as the one in column (3) of Table 4. Table 9 is a summary of the values for the coefficients corresponding to the interaction of birth year dummies with the defect prevalence at the section level. Finding significant coefficients for cohorts born in 1925-1926, similar to those of Table 4, would cast doubt on our results from the previous regressions.

As can be seen from Table 9, the time pattern for high goiter regions is replicated exactly (positive and significant coefficient for those born in 1925 and 1925) in only six of 58 defects: exophthalmic goiter, hemophilia, multiple sclerosis, acromegaly, tabes dorsalis, and curvature of the spine. Exophthalmic goiter is a more acute version of simple goiter, which we have been using in our previous specifications. The fact that its coefficients are similar to those of simple goiter is a good validity

Table 6: Logit results of initial goiter level interacted with birth year dummies

	(1)	(2)	(3)	(4)
	Air Force dummy	Air Force dummy	Air Force dummy	Air Force dummy
goiter X birthyear20	0.0132	0.00735	0.01556	0.00964
	[0.00662]*	[0.01100]	[0.00750]*	[0.01174]
goiter X birthyear21	0.02062	0.01873	0.0224	0.02044
	[0.00722]**	[0.00988]	[0.00797]**	[0.01046]
goiter X birthyear22	0.01211	0.00858	0.01329	0.00972
	[0.00615]*	[0.00928]	[0.00647]*	[0.00958]
goiter X birthyear23	-0.00147	-0.00554	-0.00088	-0.00497
	[0.00288]	[0.00292]	[0.00294]	[0.00296]
goiter X birthyear25	**0.03754**	**0.03297**	**0.03694**	**0.0324**
	[0.01276]**	**[0.00842]****	**[0.01248]****	**[0.00828]****
goiter X birthyear26	**0.03905**	**0.03527**	**0.03787**	**0.03412**
	[0.01746]*	**[0.01237]****	**[0.01690]***	**[0.01219]****
goiter X birthyear27	0.00709	0.00037	0.00532	-0.00134
	[0.01138]	[0.00776]	[0.01062]	[0.00740]
goiter X birthyear28	-0.0211	-0.02544	-0.02347	-0.02773
	[0.01000]*	[0.01356]	[0.00982]*	[0.01314]*
goiter X year of birth	-0.00059	-0.00057		
	[0.00031]	[0.00023]*		
Birth year X Enlistment Year Dummies	YES	NO	YES	NO
Birth year dummies	NO	YES	NO	YES
Enlistment month dummies	NO	YES	NO	YES
Section dummies	YES	YES	YES	YES
Constant	-2.20675	-0.59892	-2.18858	-3.42273
	[0.59722]**	[0.18681]**	[0.60949]**	[0.20194]**
Observations	2275622	2274698	2275622	2274698

* significant at 5%; ** significant at 1%
Standard errors in brackets, clustered at the state-section level
Regressions (1) and (3) - white men enlisted in the period 1940-1946
Regressions (2) and (4) - white men enlisted in the period July 1940- December 1946

Table 7: Logit results of high-goiter group dummy interacted with birth year dummies

	(1) Air Force dummy	(2) Air Force dummy	(3) Air Force dummy	(4) Air Force dummy
highgoiter X birthyear20	-0.25107	-0.42923	0.16764	-0.01719
	[0.10312]*	[0.19089]*	[0.09757]	[0.19335]
highgoiter X birthyear21	0.02616	-0.09918	0.34019	0.20985
	[0.10400]	[0.15833]	[0.10696]**	[0.16080]
highgoiter X birthyear22	0.01727	-0.10447	0.22662	0.10155
	[0.09485]	[0.13124]	[0.09843]*	[0.13312]
highgoiter X birthyear23	-0.09949	-0.14021	0.00519	-0.0372
	[0.03256]**	[0.04119]**	[0.03295]	[0.04106]
highgoiter X birthyear25	**0.60413**	**0.4365**	**0.49945**	**0.33349**
	[0.16388]**	**[0.10208]****	**[0.16002]****	**[0.10131]****
highgoiter X birthyear26	**0.8798**	**0.74234**	**0.67044**	**0.53632**
	[0.18410]**	**[0.12199]****	**[0.17565]****	**[0.11999]****
highgoiter X birthyear27	0.54155	0.36096	0.22752	0.05193
	[0.12685]**	[0.08787]**	[0.11617]	[0.08373]
highgoiter X birthyear28	0.13087	-0.01788	-0.28785	-0.42992
	[0.13545]	[0.20632]	[0.14515]*	[0.20574]*
highgoiter X year of birth	-0.10468	-0.10301		
	[0.00495]**	[0.00334]**		
Birth year X Enlistment Year Dummies	YES	NO	YES	NO
Birth year dummies	NO	YES	NO	YES
Enlistment month dummies	NO	YES	NO	YES
Section dummies	YES	YES	YES	YES
Constant	-2.40148	0.41482	-3.36703	-2.05741
	[0.59429]**	[0.12229]**	[0.72408]**	[0.13248]**
Observations	2275622	2274698	2275622	2274698

* significant at 5%; ** significant at 1%
All regressions include state-section level dummies
All regressions clustered at the state-section level
Regressions (1) and (3) - white men enlisted in the period 1940-1946
Regressions (2) and (4) - white men enlisted in the period July 1940- December 1946

Table 8: Marginal Probabilities of logit results of high-goiter group dummy interacted with birth year dummies

	[1]	[2]	[3]	[4]
variable	**dy/dx**	**dy/dx**	**dy/dx**	**dy/dx**
highgoiter X birthyear20*	-0.02077	-0.03077	0.016192	-0.00144
	[-2.68]	[-2.65]	[1.62]	[-0.09]
highgoiter X birthyear21*	0.002398	-0.00805	0.03502	0.019134
	[0.25]	[-0.65]	[2.82]	[1.21]
highgoiter X birthyear22*	0.001578	-0.00846	0.022386	0.00889
	[0.18]	[-0.83]	[2.11]	[0.73]
highgoiter X birthyear23*	-0.0087	-0.01119	0.000472	-0.00309
	[-3.17]	[-3.56]	[0.16]	[-0.92]
highgoiter X birthyear25*	**0.068926**	**0.043587**	**0.054817**	**0.031998**
	[3.01]	**[3.63]**	**[2.63]**	**[2.9]**
highgoiter X birthyear26*	**0.110453**	**0.083019**	**0.078164**	**0.055527**
	[3.66]	**[4.72]**	**[3.08]**	**[3.68]**
highgoiter X birthyear27*	0.060258	0.034958	0.022516	0.004463
	[3.54]	[3.59]	[1.8]	[0.61]
highgoiter X birthyear28*	0.012494	-0.0015	-0.02339	-0.03061
	[0.92]	[-0.09]	[-2.21]	[-2.47]

(*) dy/dx is for discrete change of dummy variable from 0 to 1
Standard errors of z statistic in brackets

Table 9: Summary of coefficients for falsification exercise with all defects

	Positive and significant coefficient		**Negative and Significant coefficient**	
	Diseases	**Total**	**Diseases**	**Total**
Disease X born in 1920	leukemia, general diseases (other), tobes dorsalis, paralysis (unknown location and cause), neuro-circulatory asthenia	5	diabetes mellitus, paraplegia, neurasthenia, tic	4
Disease X born in 1921	simple goiter, leukemia, tobes dorsalis, neuro-circulatory asthenia	4	pelagra, idcarriers, syphilis, addison's disease, paraplegia, tic	6
Disease X born in 1922	leukemia	1	mycosis, pelagra, syphilis, rickets, tumors benign, addison's disease, anemia, tic	8
Disease X born in 1923	obesity, monoplegia	2	dysentery, pelagra, tb suspected, rickets, tumors benign, arthritis, diabetes mellitus, anemia, muscular rheumatism, huntington's chorea	10
Disease X born in 1925	simple goiter, exophthalmic goiter, curvature of the spine, acromegaly, ductless glands, hemophilia, tabes dorsalis, multiple sclerosis	8	pelagra, syphilis, gonococcus, arthritis, paralysis (unknown location and cause), huntington's chorea	6
Disease X born in 1926	simple goiter, exophthalmic goiter, curvature of the spine, acromegaly, hemophilia, alcoholism, tobes dorsalis, multiple sclerosis	8	dysentery, pelagra, syphilis, gonococcus, arthritis, gigantism, drug addiction, paralysis (unknown location and cause), huntington's chorea, hysteria	10
Disease X born in 1927	syphilis, huntington's chorea	2	obesity, purpura, drug addiction, herniplea and apoplexy, paralysis (unknown location and cause), neurasthenia, hysteria, migraine	8
Disease X born in 1928	dysentery, pelagra, syphilis, gonococcus, cancer, tumors benign, arthritis, huntington's chorea, hysteria	9	simple goiter, exophthalmic goiter, idother, curvature of the spine, obesity, alcoholism, drug addiction, tobes dorsalis, neurasthenia, neurosis	10

Table 10: Falsification Exercise with Different Diseases

	(1) Simple Goiter	(2) Exophthalmic Goiter	(3) Dysentery	(4) Epilepsy
	Air Force dummy	Air Force dummy	Air Force dummy	Air Force dummy
disease X birthyear20	0.00132	-0.00009	0.07478	-0.00252
	[0.0007]	[0.002]	[0.0826]	[0.0030]
disease X birthyear21	0.002	0.00339	0.01929	-0.00188
	[0.0007]**	[0.002]	[0.0748]	[0.004]
disease X birthyear22	0.00124	0.00004	0.02241	-0.00456
	[0.0008]	[0.002]	[0.0910]	[0.003]
disease X birthyear23	-0.00024	-0.00016	-0.05137	0.00055
	[0.0003]	[0.0006]	[0.0214]*	[0.0007]
disease X birthyear25	0.00345	0.01293	-0.11918	-0.00299
	[0.0011]**	[0.0032]**	[0.0745]	[0.0027]
disease X birthyear26	0.00527	0.01852	-0.26338	0.00131
	[0.0023]*	[0.0051]**	[0.0950]**	[0.0042]
disease X birthyear27	0.00021	0.00108	-0.00325	-0.00136
	[0.0008]	[0.0025]	[0.0465]	[0.0016]
disease X birthyear28	-0.00432	-0.01221	0.275	0.00175
	[0.0016]**	[0.0045]**	[0.1253]*	[0.0055]
Constant	0.05618	0.05447	0.05702	0.06414
	[0.0368]	[0.0377]	[0.0365]	[0.0376]
Observations	2275622	2275622	2275622	2275622
R-squared	0.13	0.13	0.13	0.13

* significant at 5%; ** significant at 1%
All regressions clustered at the state-section level
All regressions include state-section level dummies
All regressions include section fixed effects, and birth year x enlistment year fixed effects.

check of our results. Hemophilia, multiple sclerosis, acromegaly, and tabes dorsalis are very rare and many sections report no cases of these defects. Curvature of spine correlates highly with goiter and may be related to iodine deficiency. The coefficient for ductless glands jumps for the 1925 cohort, but remains insignificant afterwards. Ductless glands are directly related to the function of the endocrine system, which is affected by the lack of iodine. Surprisingly enough, the coefficient for alcoholism jumps significantly for the 1926 cohort, whereas it is negative and significant for the 1928 cohort, similarly to the coefficient for goiter. Alcoholism had a much lower prevalence than goiter, however (its maximum value was 1.82, compared to 29.85 for goiter), and it was absent (or, at least, not recorded) in one third of the sections. Interestingly, cretinism, which is a consequence of severe iodine deficiency, has the same pattern of coefficients as goiter, though the jump is not significant.

In Table 10 we report the results for epilepsy and dysentery alongside our baseline simple goiter results. We also include the regression results for exophthalmic goiter, as a second measure of goiter. We choose to report epilepsy because it is a hereditary defect and does not depend on geographical factors in the way that iodine deficiency does. We also included dysentery in this falsification exercise, because it is a defect affected by general sanitation and health conditions. Exophthalmic goiter coefficients closely follow those of simple goiter. For epilepsy, no coefficient comes in significantly. In case of dysentery, we get a big negative jump for people born in 1926, whereas we get a big positive coefficient for 1928. We are still unclear why we are getting such big and changing coefficients, but we note that almost 60% of sections had no reported cases of dysentery.

7 Interpretation

How large are these effects? The highest goiter places have goiter rates of 30. The coefficients (from Table 4) suggest that about 15% more recruits from the highest goiter regions go into the AAF after salt iodization. From Appendix A we know that the Air Force recruits have, on average 9 point higher AGCT scores (almost a half a standard deviation). The average increase for the recruits from that section is therefore 0.15 time 9 points, or 1.35. So the average cognitive ability in the section goes up by greater than one twentieth of a standard deviation.

Examining the high-low regressions yields similar figures. In the high goiter group, we have a 5-10 percent higher assignment rate to the AAF after salt iodization. Ten percent times 8 AGCT points results in 0.8 points higher on average, or about a twentieth of a standard deviation. This implies a twentieth of a standard

deviation increase in cognitive ability for 25 percent of the US population.

8 Conclusion

The results suggest relatively modest effects at the population level in the US. However, for the one half a percent of US residents with a serious goiter the impact was likely quite large. For a larger population, more modest, but still positive impacts were seen. Our results show that there were measurable cognitive benefits from iodizing salt that went beyond the obvious effect of reducing goiter in the US.

These results must be seen in the context of many, many other health interventions that were happening at the same time. Ten interventions of the magnitude of iodizing salt will generate a very large and noticeable effect on overall cognitive ability.

Many countries have goiter rates that are much larger than those seen in the US. The effect of successful iodization programs in these regions would likely be larger than we see in the US.

Appendix A:
Average AGCT scores for the AAF versus the AGF

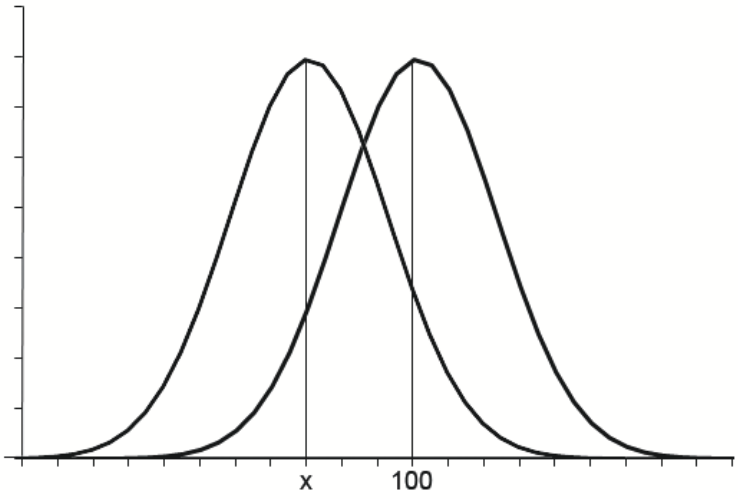
From February 1942 until August 1, 1942 the AAF was assigned 75 percent of their men from those scoring higher than average on the AGCT. The test was normed to have a mean of 100 and a standard deviation of 20. Assuming the test is distributed N(100,20), conditional on scoring above the median, the mean score is 116. Conditional on scoring below the median, the mean score is 84. This implies that the AAF has an average test score that is a 75/25 percent weighted average of these two scores for an average score of 108.

If the AAF score average were above 100, this implies that the average AGF recruit was below 100. During the war, the total proportion of enlistees from each birth cohort assigned to the AAF varied from 10 to 16 percent. If, for example, the AAF took 10% of all enlistees with an average test score of 108, this implies that the AGF got the other 90% and that this group has an average AGCT of roughly 99.

On August 1, 1942 the 75 percent rule was rescinded and the proportions went to 55/45. Similar to the calculations above this implies an average AGCT for the AAF of 102 during this period.

From December 1942 until June 1943 the AAF received 55 percent of their recruits from the pool with above average scores on both the AGCT and the ME test. We are also told that only 37.5 percent had above average scores on both. If we assume that the MA and AGCT tests are jointly normally distributed with a correlation of 0.70 we obtain a joint distribution where 37.5 of the observations are above the average on both tests. Among the pool of observations where both test scores are above average, the average AGCT score should be 0.91 standard deviations above the mean, corresponding to a test score of roughly 118. The pool of observations with either test below average has an average AGCT score 0.55 below the mean or roughly 89. Therefore the AAF recruits on average had an AGCT score 0.55*118+0.45*89 ˜105 during this period.

Figure 20: Shift in the IQ distribution of high-goiter areas after iodization



Appendix B:
Interpretation of the coefficients:
What was the IQ increase following iodization?

We are assuming that the IQ of recruits from non-goitrous areas was distributed normally, with mean $\mu = 100$ and standard deviation $\sigma = 15$. The IQ distribution of recruits from goitrous areas was also distributed normally, with a standard deviation also equal to $\sigma = 15$. We are looking for the mean of the IQ distribution of recruits from goitrous areas. Call that x. Iodization shifted the IQ distribution of recruits from goitrous areas to the right, increasing their mean IQ to 100 (Figure 20).

Let α be the % of enlistees going to AAF.

Let p be the % of AAF enlistees who scored over the median, which was 100, in the AGCT. This is based on Army rules, e.g. p=75% of enlistees in the AAF had to have scores over 100 in the AGCT (later p=55%, then p went back up). Suppose that the same percentage of AAF enlistees had IQ scores over the mean. The mean IQ of the population prior to iodization, assuming that 25% of recruits came from goitrous areas, is: $0.75 \cdot 100 + 0.25 \cdot x$.

Let e be the increase in the probability of joining the AAF for recruits from goitrous areas following iodization. This is the effect that we estimate in our regressions.

Since e is the effect of iodization, then prior to iodization, a percentage $z = \alpha - e$

of recruits from goitrous areas went to the AAF.

Let r be the % of enlisted men scoring above the mean IQ ($= 0.75 \cdot 100 + 0.25 \cdot x$), who joined the AAF.

Then, $\frac{1-p}{p} \cdot r$ is the % of enlisted men scoring below the mean IQ, who joined the AAF.

By definition, the following holds:
$\frac{1}{2} \cdot r + \frac{1}{2} \cdot \frac{1-p}{p} \cdot r = \alpha \Rightarrow r = 2 \cdot \alpha \cdot p$ and $\frac{1-p}{p} \cdot r = 2 \cdot \alpha \cdot (1-p)$

[For example, if 15% of enlistees go to the AAF and the 75%-25% rule holds, then 22.5% of the enlistees whose IQ was higher than average, and 7.5% of enlistees whose IQ was below average went to the AAF.]

Let y be the percentage of people from iodine-deficient regions, who had IQ higher than average. A percentage r of those people joined the AAF (where $r = 2 \cdot \alpha \cdot p$). Similarly, $(1-y)$ % of people from iodine-deficient regions had IQ's lower than average, and $\frac{1-p}{p} \cdot r = 2 \cdot \alpha \cdot (1-p)$ of these people went to the AAF.

It has to be the case that:

$y \cdot r + (1-y) \cdot \frac{1-p}{p} \cdot r = z \Rightarrow y = \frac{1}{2} - \frac{e}{(2p-1) \cdot 2 \cdot \alpha}$.

[For example, if 15% of recruits went to the AAF, the 75% rule was in effect, and iodization increased the probability of joining the AAF by 5 percentage points, then approximately 17% of recruits from goitrous areas had IQ levels that were higher than average, and 22.5% of them went to the AAF.]

So, we need to find the mean x of the normal distribution with $\sigma = 15$, for which y % of observations are above $0.75 \cdot 100 + 0.25 \cdot x$. In essence, we are looking for a fixed point.

Let w be the critical value in the standard normal distribution. In other words, y % of values in the standard normal distribution are over w. (In stata, $w = invnorm(1-y)$, in excel $w = norm\sin v(1-y)$).

The mean of the IQ distribution for goitrous areas prior to iodization will be:
$x = 0.75 \cdot 100 + 0.25 \cdot x - 15 \cdot w \Rightarrow x = 100 - 20 \cdot w$.

[Using the above example, it turns out that the mean of the IQ distribution in high-goiter areas was $x = 80.65$. In other words, iodization increased average IQ in iodine-deficient areas by almost 20 points, which corresponds to an increase in average IQ by 1.3 standard deviations.]

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