# The Economic Effects of Micronutrient Deficiencies:
# The case of iodine.

by
Dimitra Politi
B. A., Athens University of Economics and Business, 2002
M. A., Brown University, 2004

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This dissertation by Dimitra Politi is accepted in its present form by the Department of Economics as satisfying the dissertation requirement for the degree of Doctor of Philosophy.

Date ______________ ________________________________________
David N. Weil, Director

Recommended to the Graduate Council

Date ______________ ________________________________________
Kenneth Chay, Reader

Date ______________ ________________________________________
Yona Rubinstein, Reader

Approved by the Graduate Council

Date ______________ ________________________________________
Sheila Bonde
Dean of the Graduate School

# Vita

The author was born in Rethymno, on the island of Crete, Greece, on August 11th, 1980. She graduated from The 2nd High School of Rethymno in 1998, and moved to Athens, Greece, where she attended Athens University of Economics and Business (AUEB). During the 2000-2001 academic year she was an Erasmus Exchange Student in Economics at Université de Paris I - Panthéon - Sorbonne in Paris, France. She returned to Athens in 2001, and in 2002 she graduated with a B.A. from AUEB's Department of International and European Economic Studies, where she majored in International Economics and Finance. In August 2003 she moved to Providence, RI, and began her doctoral studies in the Department of Economics at Brown University. After completing the requirements for her Master's degree in Economics in 2004, she began working on the link between health and economic growth under the guidance of Prof. David N. Weil. She also assumed teaching responsibilities as a primary instructor and a teaching assistant for various undergraduate economics courses. In 2006 she completed *The Teaching Certificate I Program: The Sheridan Teaching Seminar*, awarded by Brown University's Sheridan Center for Teaching and Learning. This dissertation represents the culmination of her efforts to complete the requirements for the Degree of Doctor of Philosophy in the Department of Economics at Brown University.

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*To my family.*

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# Chapter 1

# The Impact of Iodine Deficiency Eradication on Schooling: Evidence from the Introduction of Iodized Salt in Switzerland

## 1.1 Introduction

Health is an important determinant of a population's prosperity and economic outcomes. Healthier people make better workers, and cross-country differences in health account for a significant part of cross-country income inequality (see Weil (2007)). Nutrition is inextricably linked to a population's health capital. Malnutrition, especially when it occurs early in life, can have serious detrimental effects on a person's lifetime productivity and economic prospects. Micronutrient deficiencies are a common source of malnutrition, caused by insufficient intake of necessary vitamins and minerals. Iodine is one such micronutrient.

Iodine deficiency is the leading cause of preventable mental retardation in the world. The WHO estimates that nearly 50 million people suffer some degree of mental impairment due to iodine deficiency[1]. 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 [2]. Despite efforts to decrease the prevalence of iodine deficiency in the 1990s, there are still 38 million children born annually at the risk of developing iodine deficiency disorders. The most vulnerable areas in the world are South Asia and Central and Eastern Europe (UNICEF 2008).

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

[2]Source: de Benoist, Andersson, Egli, Takkouche and Allen, eds (2004).

Iodine Deficiency Disorders (IDD) is a generic name given to all defects resulting from a lack of iodine in the diet. The consequences of iodine deficiency are both visible and invisible; cretinism, goiter, short stature, and deaf-mutism are among the defects related to iodine deficiency that are easily detectable. However, iodine deficiency in utero and the first three months of life results in various degrees of brain damage that might be harder to observe in an affected population. In a meta-analysis of 21 studies, Bleichrodt and Born estimate that eliminating iodine deficiency increases average IQ by 13.5 points (Bleichrodt and Born 1994). Such an improvement in cognitive ability should be reflected in economic outcomes through increased human capital in the form of health, which will affect one's educational attainment and labor productivity.

This paper estimates the effects of iodine deficiency eradication on schooling, using data from Switzerland. Switzerland, due to its geography, had a high prevalence of iodine deficiency, and it was the first country in the world to introduce iodized salt in 1922. Iodized salt proved a cost-effective measure to eradicate visible goiter, deaf-mutism, and cretinism, which were endemic before its introduction. The invisible effects of iodine deficiency on mental development and cognitive ability were not fully understood at the time, and public health authorities did not know that they were fighting against mental retardation as well as endemic goiter. As a result of the countrywide iodization campaign, there were no more endemic cretins born after 1930, deaf-mutism rates dropped significantly, and goiter disappeared in children and young recruits (Bürgi, Supersaxo and Selz 1990). I find that, apart from these effects, salt iodization also had a significant impact on graduation rates of those born in highly-deficient areas.

I use microdata from the comprehensive 1970 Swiss Census, combined with data on the pre-existing variation of iodine deficiency across 185 Swiss districts. I identify the effect of iodization on the probability of graduating from upper-secondary and tertiary education in three different ways. First, I look at the education of cohorts born before and after iodized salt first became available in 1922. I examine high- and low- goiter districts separately, since I expect high-goiter areas to be more affected by iodization. Second, I corroborate my findings by taking advantage of differences in the timing of adoption of iodized salt across cantons. Using annual, canton-level data on iodized salt sales as a percentage of total salt sales, I examine how the penetration of iodized salt affected schooling outcomes of cohorts exposed to differential degrees of iodine treatment. Finally, I use a fuzzy regression discontinuity design, where I identify the effect of iodization by looking at sudden jumps in iodized salt sales, and then compare education outcomes for cohorts born right before and right after the jump.

The introduction of iodized salt in Switzerland was the first major nutritional intervention to ever take place, yet its productivity effects have not been estimated. Given that iodine deficiency is still a problem in much of the developing world, it is useful to know how Swiss productivity was affected by the introduction of iodized salt.

This paper's contribution can also be seen from a different perspective. The successful campaign for the eradication of iodine deficiency provides a rare opportunity to examine the effects of an "injection of IQ" on schooling outcomes. Iodization had a significant impact on the cognitive ability of people born in the worst-afflicted regions of Switzerland. Heckman and Vytlacil (2001) describe some problems in the identification of returns to schooling, apart from the usual omitted-ability bias. The real problem, they note, "is that ability and schooling appear to be inseparable –all interaction and no main effects– even if ability is perfectly observed". The advent of iodized salt made whole cohorts, namely those born after the intervention in previously deficient areas, smarter, through its effect on brain development in utero. In this light, by using the eradication of iodine deficiency as a shock to cognitive ability in Switzerland, we can decouple ability and schooling levels, and study the effects of the former on the latter.

I find that iodization increased the probability of graduating from upper-secondary and tertiary education for those born in previously highly-deficient areas by around 1 percentage point[3]. I also find that these results are driven by the effect of iodization on females, where iodization explains between 9 and 14% of the total change in graduation rates from upper education levels over this period. This could be due to cross-gender differences in the impact of intrauterine iodine deficiency on brain development. In this case, the same level of iodine treatment will have different effects in male and female fetuses, which will translate into different effects on schooling later in life. This is consistent with medical evidence showing that females are more prone to thyroid disorders than men[4]. However, the same findings could be explained by household differences in the sensitivity of schooling decisions to changes in cognitive ability for male and female offspring. In this case, a given increase in cognitive ability might raise female schooling by more than male schooling.

Overall, there is strong evidence that eradicating iodine deficiency had a significant impact on the educational attainment of cohorts born after the introduction of iodized salt in those regions where one would expect to find such an effect, namely regions which were highly deficient prior to the intervention.

The rest of the paper is organized as follows: section 1.2 provides a short review of the relevant literature from Economics. Section 1.3 provides some background on iodine deficiency disorders, and section 1.4 describes the campaign for salt iodization in Switzerland. Section 1.5 describes the data from the 1970 Swiss Census, as well as the dataset on the pre-existing prevalence of iodine deficiency across Swiss municipalities. Section 1.6 introduces additional data, which show the decline in deaf-mutism following the introduction of iodized salt. Sections 1.7, 1.8, and 1.9 describe the identification strategy and contain the empirical findings. Section 1.10 provides an interpretation of the results, and section 1.11 concludes.

[3]Primary and lower-secondary education in Switzerland were obligatory and universal during the period that I examine, therefore it is not surprising that iodization did not affect graduation rates from these lower education levels.

[4]Thyroid-related disorders are directly linked to iodine intake, because the thyroid gland is where most of the body's stock of iodine is stored and used in the production of hormones which regulate metabolism.

## 1.2 Related literature

I explore the link from better health to improved economic performance by quantifying the effects of a wide-reaching public health intervention. Other papers exploring the economic effects of smaller-scale interventions are, for example, Miguel and Kremer (2001), who study the effects of introducing deworming drugs in Kenyan schools, taking into account the positive externalities arising from lower infection rates. In addition, Bleakley (2006) examines the effects of eradicating hookworm in the American South, and also finds positive effects on school attendance and future earnings. Finally, Lucas (2006) studies the effects of malaria eradication, and finds evidence of increased female educational attainment and female literacy as a result of the lower prevalence of the disease.

I concentrate attention on the effects of irreversible mental damage resulting from iodine deficiency in utero and the first three months of life. In that respect, this paper is closely related to the economic literature on the importance of fetal and early age health inputs on subsequent economic outcomes. One example of this literature is Douglas Almond's paper on the long-lasting effects of the Spanish Influenza of 1918 (Almond 2006). Using U.S. Census data, Almond exploits the sharp timing and the geographic variation in the severity of the pandemic. He finds that the cohorts exposed to the virus in utero display lower education attainment rates, lower income and socioeconomic status, higher rates of physical disability and increased dependence on state transfer programs. In another paper, Case and Paxson (2008) highlight the importance of in utero and early childhood health inputs for the adult height of an individual, which in turn is associated with higher earnings. In particular, taller children perform better on cognitive ability tests, and this higher performance explains a big part of the variation in earnings later in life.

## 1.3 Background on Iodine Deficiency Disorders

Iodine is a necessary micronutrient, found in very small quantities in the human body[5]. Most of the body's iodine is located in the thyroid gland. Iodine is essential in the synthesis of the two thyroid hormones, thyroxine (T4) and Triiodothyronine (T3). These two hormones regulate metabolism and "play a determining part in early growth and development of most organs, especially of the brain" (Delange 2001).

When the thyroid does not receive sufficient amounts of iodine it adapts by enlarging in order to maximize the use of available iodine. This enlargement is called a goiter. Goiters can occur at any point in one's lifetime, whenever the iodine intake is not sufficient[6]. Some goiters are reversible, especially in young individuals. By providing iodine to schoolchildren, numerous studies have shown that their goiters disappeared (see, for example, Marine and Kimball (1921) for details on their 1917

[5] The recommended daily intake of iodine is $50\mu g$ for people aged 0-6 months, $90\mu g$ for people aged 6 months-6 years, $120\mu g$ for ages 7 to 10, $150\mu g$ during adolescence and adulthood, and $200$-$300\mu g$ during pregnancy and lactation (World Health Organization 1996).

[6] For adults, adequate iodine intake is in the range of $100$-$199\mu g$/day. There are three degrees of iodine deficiency: mild ($50$-$99\mu g$/day), moderate ($20$-$49\mu g$/day) and severe ($<20\mu g$/day) (ICCIDD, UNICEF and WHO 2001, Table 5, p.36.).

experiment in Akron, Ohio). Reversing goiter in adults is harder, especially when they have been subject to iodine deficiency for many years.

Goiter is a visible effect of iodine deficiency. Apart from goiter, however, iodine deficiency can have irreversible and harder to observe consequences if it occurs in utero and in the first three months of life. If production of the thyroid hormones is affected by lack of iodine, normal development of the fetus or the infant is put at risk. Inadequate iodine intake on the part of the pregnant mother results in mental retardation for the newborn, and it is associated with a higher incidence of abortions, stillbirths, low birth weight and increased perinatal and infant mortality[1]. Iodine deficiency results in various degrees of mental retardation and abnormal brain development, which might even go undetected in a population. In the worst case scenario, severe iodine deficiency causes cretinism. Cretinism is an acute condition characterized by a combination of mental retardation, stunting and physical deformation. Cretins are often deaf-mute and have goiters. 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[7]. If this is true, then iodine deficiency should have sizable economic effects for any afflicted population.

Endemic goiter and endemic cretinism are primarily due to the geographic location of a population. The main store of iodine is the ocean. As ocean water evaporates, iodine falls on the upper layers of soil through rainfall. Therefore, geographic areas close to the ocean provide adequate amounts of iodine to their population, either through the air, the drinking water, or the consumption of iodine-rich foods such as fish, seaweed, meat, or vegetables fed or grown on iodine-rich soil. On the contrary, some geographic areas are naturally iodine-poor. For example, regions subject to heavy rain may be iodine-poor due to soil erosion. Furthermore, during the last Ice Age (18,000-8,000 years ago), ground erosion brought about by glaciation stripped the soil of its iodine in some parts of the world. Because it takes thousands of years for rain water to replenish the superficial layers of soil with iodine, the iodine-content of the soil and water of those regions is extremely low. For this reason, places such as the Andes, the Alps, the Pyrenees, the Himalayas and, in general, regions that have been subjected to intense glaciation in the past, are iodine-poor (Koutras, Matovinovic and Vought 1980). Also, there are cases in which even though the soil contains iodine, the latter never reaches the population. This may happen if, for example, the morphology of the soil is such that iodine is easily absorbed by the soil, making it harder for iodine to reach the plants, and, consequently, humans[8] (Koutras 1980, p.256).

I use data on goiter prevalence among male recruits as a proxy for the underlying geographic

[7] This estimate is based on a meta-analysis of 21 studies of the effect of iodine deficiency on cognitive ability.

[8] Sporadic goiter might occur as a result of the consumption of certain foods. For example, vegetables in the Cruciferae family (such as cabbage and turnip) are known to have goitrogenic properties. Geologic factors seem responsible for the goitrogenic content of both food and water in some areas. Regular and high consumption of such foods can cause the thyroid gland to enlarge. Goiters may also be caused by an excess of iodine consumption, although this is rare. Genetic predisposition also seems to play a secondary role in the appearance of goiter. Goiters caused by these factors are sporadic and do not occur regularly in a population. On the contrary, endemic goiter and endemic cretinism are the result of iodine deficiency.

distribution of iodine deficiency. The Swiss Alps were known for the endemic nature of goiter and cretinism. The data on goiter prevalence confirm the link between iodine deficiency and goiter prevalence: the canton of Ticino ranked the lowest among cantons in goiter prevalence. This is to be expected, since Ticino is in the southernmost part of Switzerland, bordering Italy and enjoying a milder climate, proximity to the Mediterranean Sea and possibly more iodine-rich foods coming from Italy than the rest of the country. Another canton with unusually low goiter prevalence is Vaud. Historically, Vaud had an exclusive salt mine, which was rich in iodine (Bürgi et al. 1990, p.581). After iodized salt was introduced in Switzerland, cretinism was eradicated and goiters disappeared from the younger generations, further proving that it was iodine deficiency that caused these abnormalities in the population.

Iodine has been explicitly used in the treatment of goiter ever since Bernard Courtois isolated it as an element in 1811[9]. The idea that endemic goiter is due to iodine deficiency was first put forward in 1846, by Jean-Louis Prévost and A.C. Maffoni (Prévost and Maffoni 1846). Even though cretinism was associated with endemic goiter, the crucial role of iodine in mental development was not understood until more than a century later. When large-scale interventions of iodine supplementation took place around the 1920s and after, the objective was goiter eradication. People did not know that they were also fighting against mental retardation.

After doctors started prescribing iodide to their patients in order to fight goiter, toxic side-effects resulting from over-dosing triggered opposition to the universal use of iodine. It wasn't until 1917 that the first larger-scale iodine supplementation program took place in Akron, Ohio. From 1917 to 1922, schoolgirls from 5th grade and above were given sodium iodide regularly, in the form of syrup, under the direction of David Marine and his assistant, O.P. Kimball. When it began, the intervention was very controversial, but its undeniable success paved the way for larger-scale programs in the USA and in Europe.

Iodized salt started circulating in Switzerland in 1922. Almost simultaneously, fortification of salt with iodine began in the USA, where iodized salt first appeared in 1924. Both interventions eliminated endemic cretinism and goiter in children, and they decreased goiter prevalence in adults, even though they were followed by an initial spike in goiter-related surgeries and deaths, which then subsided[10]. More information about the program in Switzerland is provided in the following section.

[9] However, iodine-rich foods and plants, such as seaweed, were used by ancient civilizations, such as the Chinese and the Greeks, to treat the swelling of the neck before the isolation of iodine as an element.

[10] This adverse consequence of iodine supplementation was due to the existence of nodular goiters in the population. Nodular goiters were caused by chronic iodine deficiency. Nodular goiters may become toxic following a sudden increase in iodine intake after a long period of deprivation. This side-effect of iodization is known as iodine-induced hyperthyroidism).

## 1.4 The campaign for salt iodization in Switzerland

Accounts of goiter and cretinism in Switzerland date back to antiquity[11], although the link between two conditions was not yet known until much later. Goiter was attributed to something in the water, rather than something absent from it, and it was often confounded with other diseases visible in the neck[12].

The late 18th and early 19th centuries were marked by considerable advances in medical knowledge on the thyroid and its operation. These advances were followed by increased interest in goiter and cretinism, and efforts to assess their geographical prevalence and the extent of the problem. During Napoleonic Wars, the low performance of Swiss recruits for the French Army troubled Napoleon and the local authorities in today's canton of Valais. Under Napoleon's orders, a survey was conducted, according to which there were 4,000 cretins among 70,000 inhabitants (this is an extremely high prevalence of 5.7%)[13]. Since then, other epidemiologic studies followed, usually focusing on recruits or schoolchildren. However, the standards of goiter and cretinism classification differed from author to author, so it is impossible to make meaningful comparative studies using different sources.

Nevertheless, the aforementioned studies revealed the extent of the problem. Bircher (1883), in his monograph, published goiter data taken from recruits during the period 1875-1880 for all towns and villages in Switzerland, and noticed that even localities adjacent to each other might differ a lot in their goiter prevalence. I use this rich database to construct measures of iodine deficiency across localities. In 1889, Theodor Kocher published a goiter study of schoolchildren in Bern, which revealed a total goiter prevalence ranging from 20 to 100% (Kocher 1889). Because of the great prevalence of goiter and cretinism, the medical profession and public health authorities focused attention on the etiology and on ways to provide prophylaxis to the population.

As a result, a Swiss Committee for the study of goiter was established in 1907. At that time, goiter was still attributed to some agent in the drinking water, even though experiments with iodine supplementation for the treatment of goiter were already taking place in France and, later, in the USA. Right before his death in 1917, Kocher suggested goiter treatment with small doses of iodine (Bürgi et al. 1990).

The first canton to iodize salt was Appenzell-Ausserrhoden, where iodization started in February 1922, with the initiative of a local doctor, H. Eggenberger. In June 1922, the Swiss Goitre Commission recommended the addition of small amounts of iodine in salt and the additional weekly consumption of iodine tablets by schoolchildren. Children were encouraged to take more iodine than the general population, because they were less likely to develop toxic symptoms. At the same

[11] Writers as far back as the 1st century BC wrote about a swelling of the neck, found in people living in the Swiss Alps. For example, the architect Vitruvius wrote: "[...] the Medulli in the Alps have a kind of water, from drinking which they get a swelling of the neck" (Langer 1960, p.10-11, translated from Vitruvius, P.M., *De Architectura*, lib. VIII, 3, 20).

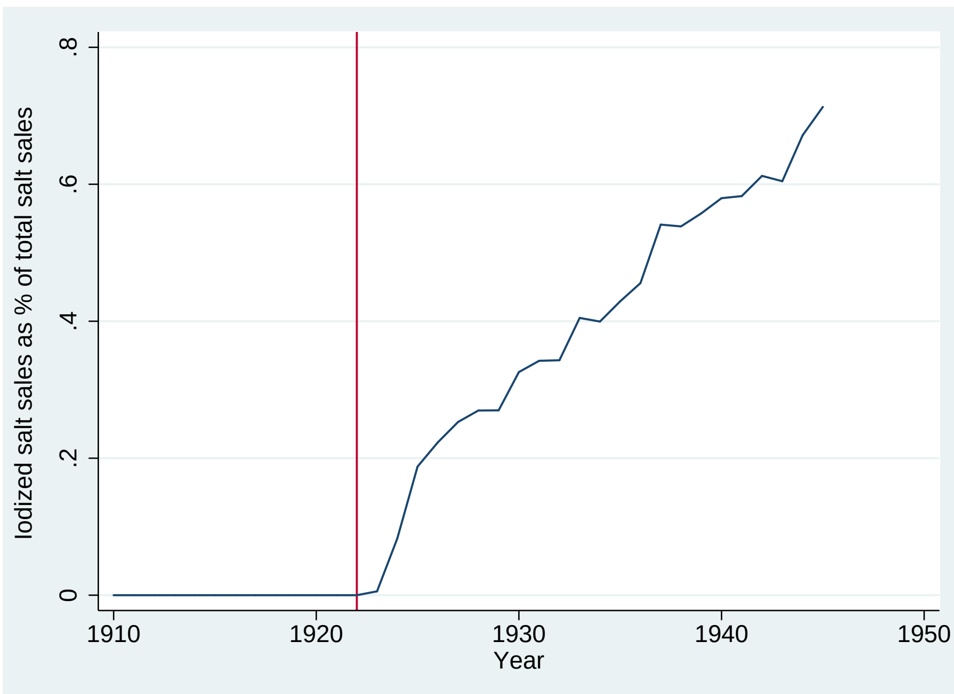
[12] For instance, some writers attributed goiter to a lack of minerals in the water or thought that it was the result of rickets. Others came closer to the true cause, linking cretinism to distance from the sea and to air quality (Langer 1960).

[13] Taken from Bürgi et al. (1990), original reference is: Merke, F. (1971) Geschichte und Ikonographie des endemisches Kropfes und Kretinismus. Berne: H. Huber.

time, consumption of the "new salt" would remain voluntary and non-iodized salt would still be available(Bürgi et al. 1990).

It was in November 1922 that United Swiss Rhine Salt Works (USRSW)[14] started adding iodine to salt (5 mg. KI or 3.75 mg. I per kg salt) and selling the new product at the same price as non-iodized salt. Even before that date, though, iodine prophylaxis had become popular, especially since Marine and Kimball's experiments with schoolchildren in the USA. After the recommendations of the Swiss Goiter Committee and the success of salt iodization in Appenzell-Ausserrhoden, the other cantons started allowing the sale of iodized salt in their markets. Figure 1.1 is a graph showing the population-weighted average iodized salt sales a a percentage of total salt sales in Switzerland. As is clear from Figure 1.1, iodized salt became popular fast.

Figure 1.1: Iodized salt penetration in Switzerland




source: *Wespi (1962) and 1970 Swiss Census*

Not all cantons introduced iodized salt simultaneously, though. For instance, Valais iodized in 1925, Zürich in 1932 and Bern in 1936[15]. On the other hand, Aargau and Basel-Land didn't iodize until 1952 and 1950 respectively. In 1925 fewer than one fourth of cantons had iodized salt sales that exceeded 60% of total salt sales. By 1945 fewer than one fourth of cantons had salt sales that were below 20% of total salt sales. By 1955, iodized salt sales exceeded 60% of total salt sales in

[14]USRSW was "the exclusive supplier of salt to 24 of the 25 cantons" of Switzerland, the exception being the canton of Vaud (Bürgi et al. 1990, p.582).

[15]This is the first year that the cantons' iodized sales exceeded 40% of total salt sales.

all cantons, and in many of them, only iodized salt was sold and consumed (Wespi 1962). On a national scale, the iodine content of salt was raised in subsequent years, to 7.5 mg. in 1962 and to 15 mg. iodide per kg salt in 1980 (Bürgi et al. 1990).

The success of the iodization program was indisputable. According to Bürgi et al. (1990), "no new endemic cretins born after 1930 have been identified" (p.577). Deaf-mutism rates fell sharply for cohorts born after 1922 (see section 1.6). In Appenzell-Ausserrhoden, which was the first canton to provide iodized salt to its inhabitants, the prevalence of goiter in newborns fell from 20% to 6.4% within the first year after iodization. The prevalence dropped further when, in later years, the iodine content of salt was raised. The beneficial effects on iodization were also seen in the increased height of 6-year-olds entering school, as well as young recruits. In the city of Lausanne, 23.7% of young recruits had large goiters in 1924/1925, but the figure had dropped to 0.2% by 1983-1987 (Bürgi et al. 1990).

## 1.5 The 1970 Swiss Census and Bircher's monograph

The main source of data is the complete 1970 Swiss Census (Federal Statistical Office 1970). Switzerland is made up of 26 cantons (comparable to US States, but much smaller), 184 districts and 2896 municipalities. The 1970 Census contains detailed information on an individual's year and municipality of birth, as well as other geographic, demographic, work and migration variables. In particular, I know the municipality and year of birth for each individual. Having detailed information on the place of birth is important, since the location of the mother during her pregnancy will determine the extent to which she got adequate amounts of iodine in her diet[16].

I limit the sample to all Swiss-born individuals interviewed in the 1970 Census, who were born before 1950. The oldest person in my sample was born in 1864. I estimate the effects of iodization both on all cohorts but also on a smaller age range, which is less likely to be affected by selection into longevity. The total number of observations is 3,086,287, comprised of 1,503,257 males and 1,583,030 females.

[16] Unfortunately, the Swiss Census asks no income questions. Swiss income data can be found in the Swiss Labor Survey or the Swiss Household Panel, but these datasets cannot be used here, because the former does not include place of birth as a question, while the latter is too recent (the first wave of interviews took place in 1999).

Table 1.1: Summary Statistics: graduation rates

| | Born before 1922 | Born after 1922 | Born before jump in iodized salt sales | Born after jump in iodized salt sales | Total |
|---|---|---|---|---|---|
| **Whole sample** | | | | | |
| Number of observations | 1,503,277 | 1,583,010 | 2,252,036 | 834,251 | 3,086,287 |
| % having completed obligatory education | 99.74% | 99.77% | 99.76% | 99.74% | 99.75% |
| % having completed secondary education | 47.00% | 61.86% | 51.14% | 64.02% | 54.62% |
| % having completed tertiary education | 9.03% | 17.02% | 11.37% | 17.88% | 13.13% |
| **Males** | | | | | |
| Number of observations | 706,047 | 797,210 | 1,084,703 | 418,554 | 1,503,257 |
| % having completed obligatory education | 99.78% | 99.78% | 99.79% | 99.74% | 99.78% |
| % having completed secondary education | 62.85% | 74.20% | 66.21% | 75.77% | 68.87% |
| % having completed tertiary education | 11.96% | 19.67% | 14.53% | 19.99% | 16.05% |
| **Females** | | | | | |
| Number of observations | 797,230 | 785,800 | 1,167,333 | 415,697 | 1,583,030 |
| % having completed obligatory education | 99.70% | 99.76% | 99.73% | 99.74% | 99.73% |
| % having completed secondary education | 32.96% | 49.33% | 37.13% | 52.18% | 41.09% |
| % having completed tertiary education | 6.43% | 14.33% | 8.43% | 15.75% | 10.35% |

Table 1.2: Summary Statistics (continued): graduation rates by region

Whole sample

| | Born before 1922 | | Born after 1922 | | Born before jump in iodized salt sales | | Born after jump in iodized salt sales | |
|---|---|---|---|---|---|---|---|---|
| | High-goiter | Other regions | High-goiter | Other regions | High-goiter | Other regions | High-goiter | Other regions |
| Number of observations | 373,156 | 1,130,121 | 402,148 | 1,180,862 | 649,013 | 1,603,023 | 126,291 | 707,960 |
| % having completed: | | | | | | | | |
| obligatory education | 99.72% | 99.74% | 99.75% | 99.77% | 99.74% | 99.76% | 99.72% | 99.75% |
| secondary education | 44.89% | 47.69% | 60.17% | 62.43% | 50.02% | 51.59% | 67.18% | 63.45% |
| tertiary education | 8.64% | 9.16% | 17.14% | 16.98% | 11.72% | 11.23% | 19.87% | 17.52% |

Males

| | Born before 1922 | | Born after 1922 | | Born before jump in iodized salt sales | | Born after jump in iodized salt sales | |
|---|---|---|---|---|---|---|---|---|
| | High-goiter | Other regions | High-goiter | Other regions | High-goiter | Other regions | High-goiter | Other regions |
| Number of observations | 176,895 | 529,152 | 202,422 | 594,788 | 316,636 | 768,067 | 62,681 | 355,873 |
| % having completed: | | | | | | | | |
| obligatory education | 99.77% | 99.78% | 99.75% | 99.78% | 99.77% | 99.80% | 99.70% | 99.75% |
| secondary education | 60.25% | 63.72% | 72.06% | 74.93% | 64.38% | 66.96% | 77.52% | 75.46% |
| tertiary education | 11.20% | 12.22% | 19.30% | 19.80% | 14.65% | 14.48% | 19.93% | 20.01% |

Females

| | Born before 1922 | | Born after 1922 | | Born before jump in iodized salt sales | | Born after jump in iodized salt sales | |
|---|---|---|---|---|---|---|---|---|
| | High-goiter | Other regions | High-goiter | Other regions | High-goiter | Other regions | High-goiter | Other regions |
| Number of observations | 196,261 | 600,969 | 199,726 | 586,074 | 332,377 | 834,956 | 63,610 | 352,087 |
| % having completed: | | | | | | | | |
| obligatory education | 99.68% | 99.71% | 99.75% | 99.76% | 99.72% | 99.73% | 99.74% | 99.74% |
| secondary education | 31.05% | 33.58% | 48.12% | 49.74% | 36.35% | 37.45% | 56.99% | 51.31% |
| tertiary education | 6.34% | 6.47% | 14.95% | 14.11% | 8.93% | 8.23% | 19.81% | 15.02% |

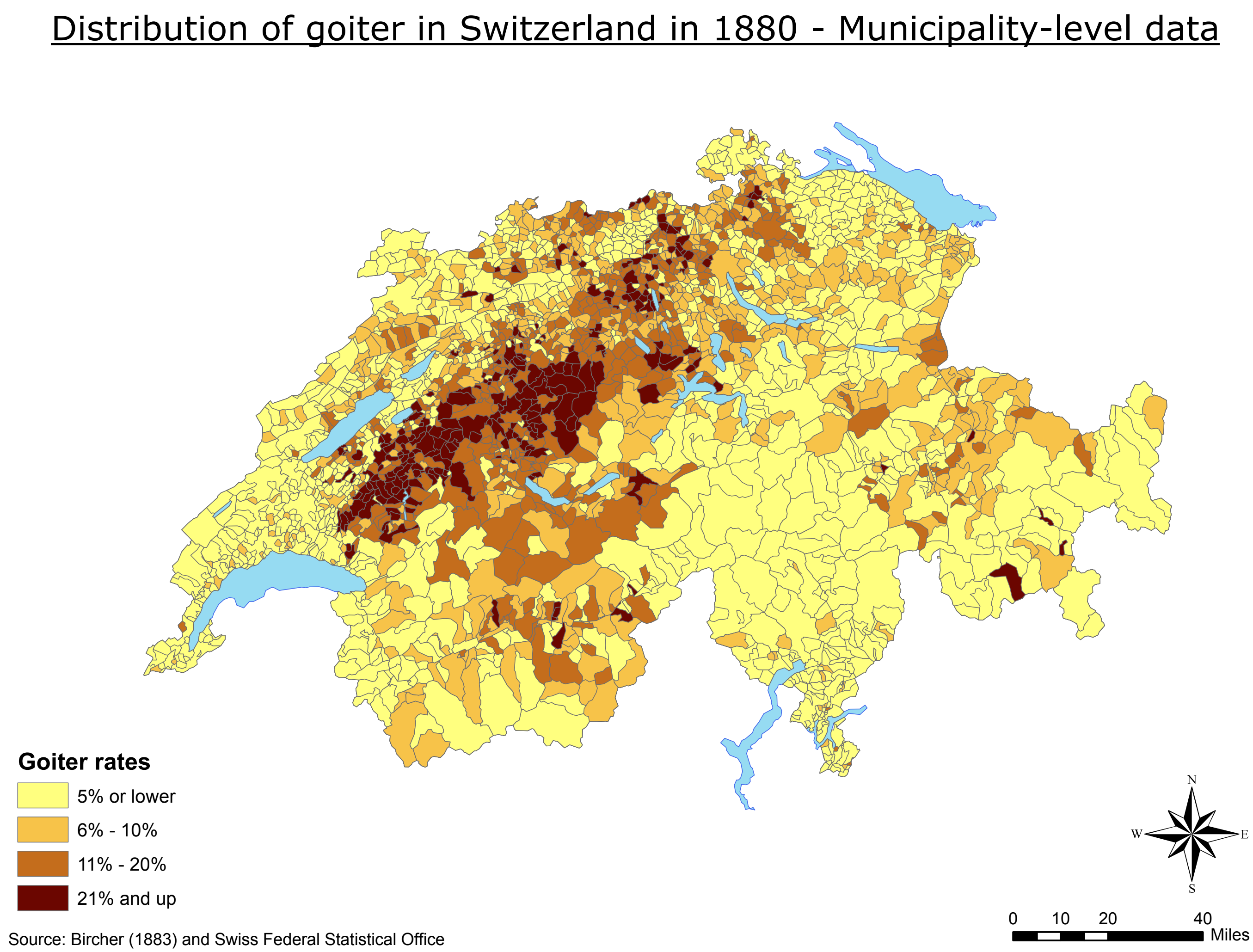
Notes: High-goiter regions are defined as those districts belonging to the top 25% of the population-weighted goiter distribution

I use two education outcomes; indicator variables for completing upper-level secondary education, and completing tertiary education. Obligatory education consists of 6 years of primary education and 3 years of lower-secondary education, and it is universal. Upper-level secondary education[17] ranges between an extra 3 to 5 years after having completed 9 years of obligatory education, depending on whether someone is preparing for university-level education or just completing a professional apprenticeship. Tertiary-level education corresponds to a minimum of 13 years of schooling, and includes studies in colleges, universities, but also upper-level vocational schools.

Tables 1.1 and 1.2 provide some summary statistics for the sample as a whole, as well as separately by gender. Obligatory education was universal; more than 99% of the population completed at least 9 years of schooling. Secondary education was less pervasive, but still rather common, as roughly one in two got to this level of schooling. When it comes to tertiary education, however, even if we look at the younger cohorts, those born after iodization, we see that only one in five men attended a higher education establishment. The rates for women are consistently lower, even though the percentage of women advancing to secondary and tertiary levels of education grew by more than the corresponding percentages for men over my period of examination.

[17] I will henceforth refer to upper-level secondary education simply as “secondary education”, but it is understood that lower-level secondary education is part of obligatory schooling in Switzerland.

Figure 1.2: Bircher's Data on goiter in recruits



I combine the Census microdata with data on the pre-existing variation of iodine deficiency in Switzerland. These data come from a monograph written by H. Bircher and published in 1883 (Bircher 1883). Bircher collected data on goiter in Swiss recruits during the period 1875-1880, for every municipality (village) in every district of every canton in Switzerland. For each locality, he listed the total number of recruits with goiter that enlisted in the 6-year period, from 1875 to 1880. Bircher also used 1880 Census data to construct measures of the underlying prevalence of goiter in the population where the recruits came from.

Because many municipalities have been divided or merged with others since Bircher's time, I construct new measures of underlying goiter prevalence in the population at the district level (one administrative level up from the municipality level), using the same method used by Bircher (Bircher 1883)[18]. Figure 1.2 is a map of Switzerland, showing the geographic variation in goiter, as depicted by Bircher's data. It is evident from the map that regions closest to the Swiss Alps were the ones that were most affected by goiter, whereas regions close to the Mediterranean were not so deficient in iodine.

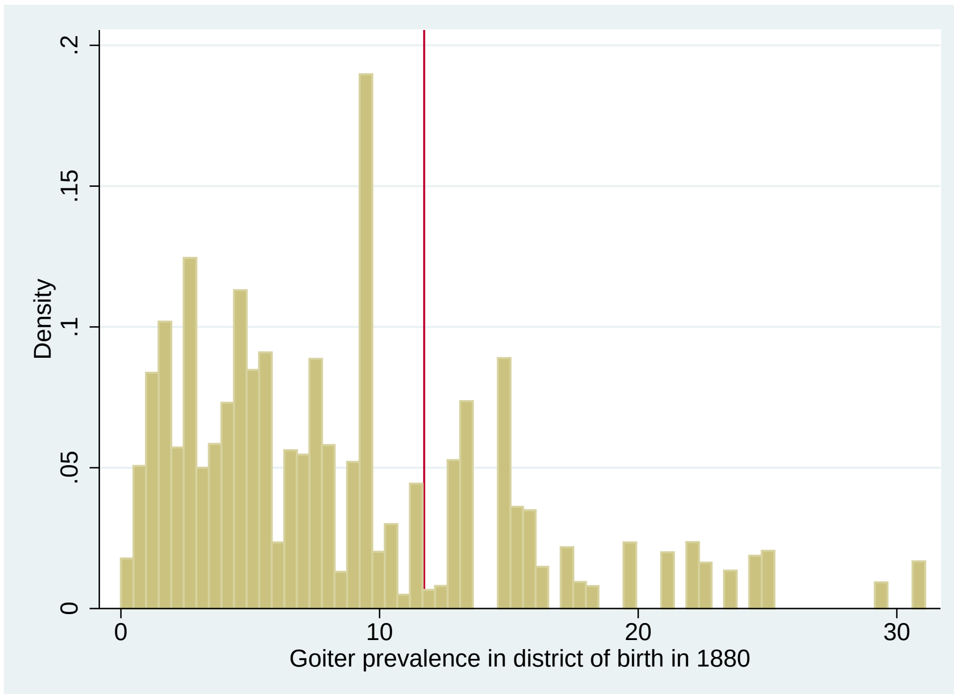
Bircher's data on goiter prevalence are old and prone to measurement error. The data were collected in 1875-1880, so that the goiter distribution in Switzerland in 1921 might have looked quite different. Also, to the extent that cretins and youths with extreme cases of goiter would not enlist in the army in the first place, the data on goiter might be understating the degree of iodine deficiency for some regions. They might also give a distorted picture of the relative position of two localities with respect to their pre-existing variation in goiter rates. For instance, a given locality with a serious iodine deficiency problem might have supplied fewer recruits than another, less-afflicted locality. In Bircher's data, the latter locality will be documented as having a more serious iodine deficiency problem compared to the locality that supplied fewer recruits because of its higher goiter and cretinism prevalence.

Although measurement error might be an issue, Bircher's data have been shown to be very good proxies for the underlying levels of iodine deficiency, in the sense that they correlated well with estimates of the iodine content of soil and water across localities, whenever such measures have been available (Bürgi et al. 1990). Bircher's goiter data also correlate with rates of deaf-mutism on the eve of iodization (see Figure 1.4 and Section 1.6). They also show that goiter rates displayed great variation, even within a given district, among villages within a small distance from each other. In any case, in order to minimize the effects of any measurement error in Bircher's data, I break the Census sample down in broad categories according to a district's goiter prevalence. Also, in some specifications I only use data in the top and bottom tail of the goiter distribution, so that the exact distribution of goiter rates doesn't matter very much.

Figure 1.3 is a population-weighted histogram of the goiter prevalence in 1880, as it appears in my sample. Each observation from the 1970 Census is matched to an observation from Bircher's data, according to one's district of birth. The red line in Figure 1.3 marks the 75th percentile cutoff

[18] Bircher's formula for constructing the prevalence of goiter in the population (in percentage terms) is: $\frac{number\_of\_goitrous\_recruits \times 100 \times 100}{6 \times population\_in\_locality}$. The ratio is divided by 6 to get the yearly average number of goitrous recruits, and it is multiplied by 100 because he estimates that 100 inhabitants supply approximately 1 recruit.

Figure 1.3: Histogram of goiter prevalence in Switzerland




source: *Bircher(1883) and 1970 Swiss Census*

in my sample, which corresponds to a goiter prevalence of 11.7%. For my analysis, I consider any district with a goiter prevalence equal to 11.7% or higher to be a "high-goiter district". Outcomes are similar when I modify this cutoff level to reflect the top 20% or 30% of the population-weighed goiter distribution.

## 1.6 Iodized Salt and the decline in deaf-mutism

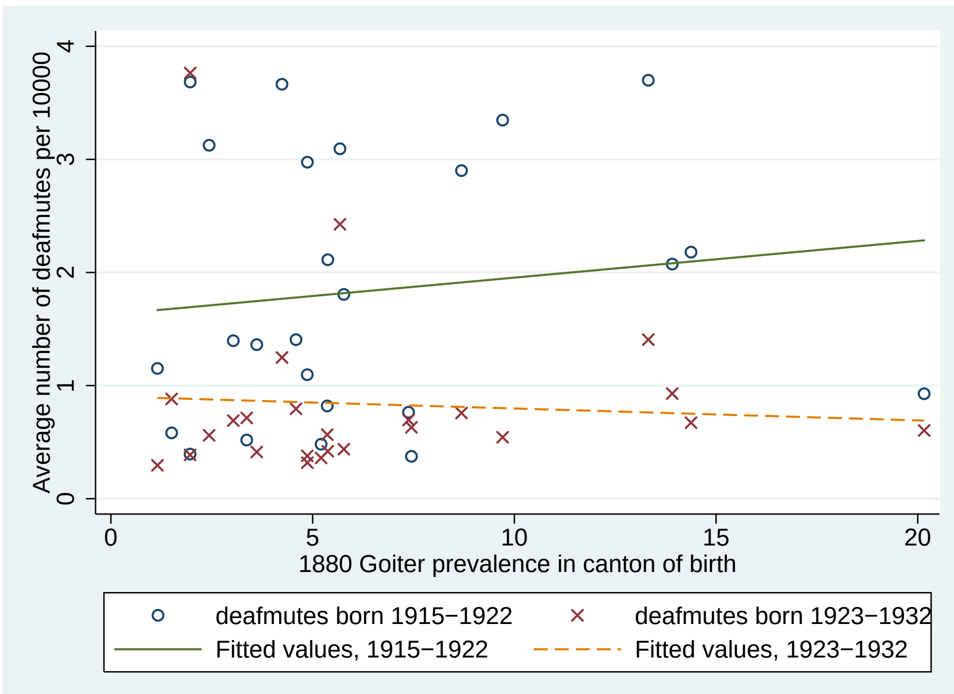
The success of the iodization campaign in Switzerland was reflected very clearly in the steep drop in the number of deaf-mutes among children born after 1922. Wespi (1945)[19] collected a near-complete count of deaf-mute schoolchildren who attended specialized institutions during the period 1922-1942, along with data on their year of birth and the residence of their parents at the time (assumed to be the children's canton of birth). Since most admissions occur at the ages 7-10, Wespi limited his analysis to children born in the period 1915-1932.

Figure 1.4 combines Wespi's data on deaf-mutism and Bircher's data on goiter prevalence in 1883 (aggregated at the canton level) in a scatterplot. I divide Wespi's data in two categories: cohorts born in 1915-1922 (before iodization), and cohorts born in 1923-1932 (after iodization). Each observation is a canton-time period combination, so that there are two observations for every

[19] I am grateful to Prof. Dr. Hans Bürgi for kindly sharing this source with me.

canton, which correspond to the same rate of goiter but different rates of deaf-mutism. As expected, rates of deaf-mutism (per 10,000 people) for cohorts born prior to iodization (1915-1922) correlate positively with rates of goiter in recruits, even though the goiter data was collected many decades earlier[20]. On the contrary, deaf-mutism rates for cohorts born after iodization (1923-1932) do not correlate at all with goiter rates, as they were recorded prior to the intervention.

Figure 1.4: Deaf-mutism and 1883 Goiter Prevalence before and after iodization

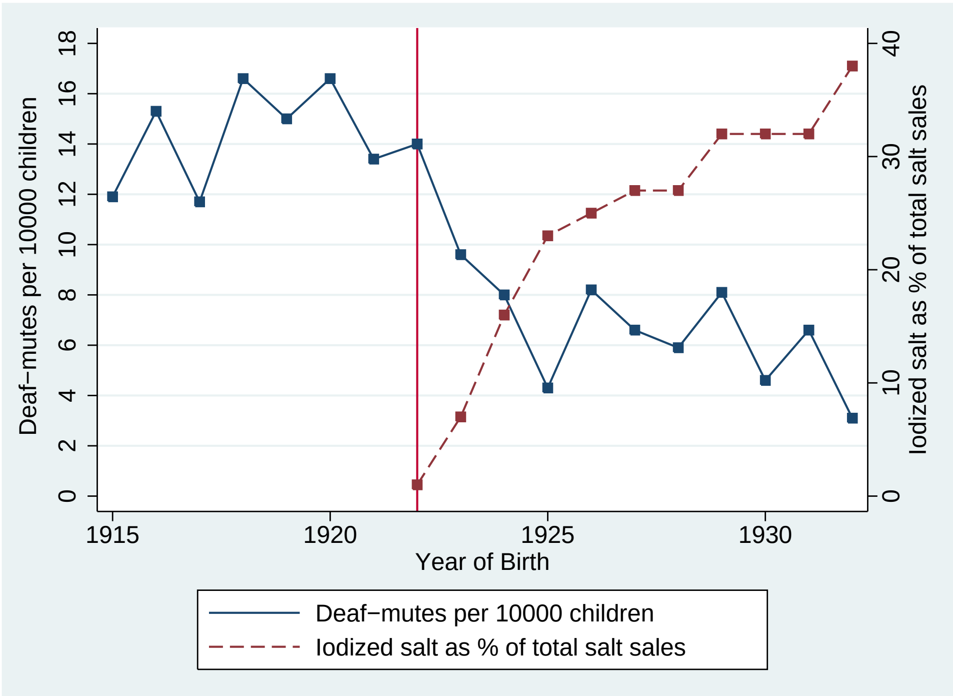



source: *Bircher (1883), Wespi (1945), and 1970 Swiss Census*

Figure 1.5 is a plot of the prevalence of deaf-mutism in each cohort born in 1915-1932, using Wespi's data, against the country-wide penetration of iodized salt. It is clear from this figure that the prevalence of deaf-mutism among schoolchildren decreased rapidly for those born after 1922, which coincides with the introduction of iodized salt.

[20]Wespi (1945) speculates that this positive relationship might even be understated, because in highly-deficient areas admission into special institutions may have been incomplete. This may have been the case if in these highly-affected areas endemic deaf-mutes also had other medical or learning impediments, preventing them from attending a school.

Figure 1.5: Deaf-mutism and Iodized Salt penetration




source: *reproduced from Wespi (1945)*

## 1.7 A first look at the data: using 1922 as the cutoff date for treatment

Iodized salt first became available in 1922. During that year, iodized salt only circulated in one of the smallest cantons of the Swiss Confederation, Appenzell-Ausserrhoden, following the initiative of a local doctor. However, the Swiss Goitre Commission was founded in 1922, and a nationwide campaign to eradicate goiters from the population was launched. Medical awareness of the potential benefits of iodine supplementation increased, and iodized salt sales picked up fast, as manifested by Figure 1.1. Rates of deaf-mutism fell rapidly after 1922 (Figure 1.5), further suggesting that this year marked the beginning of the intervention. People who were in utero during or after 1922 were clearly exposed to a different environment than those born before 1922.

In a first look at the data, I compare cohorts born before and after 1922 in a differences-in-differences framework, where I also control for a district-specific time trend. I look at the probability of graduating from secondary and tertiary education. Treated individuals are those born in high-goiter districts after 1922. A high-goiter district is identified as one being in the top 25% of the population-weighted goiter distribution[21]. I expect high-goiter districts to be the ones benefiting from the introduction of iodized salt, since underlying iodine deficiency was the most severe in those

[21]Results are similar when I consider the top 20% and the top 30% of the population-weighted goiter distribution.

regions. On the contrary, people born in low-goiter districts were less likely to benefit from the treatment, since their iodine intake in utero was already higher.

Figures 1.6 and 1.7 are regression-adjusted graphs, which show how the probability of graduating from secondary (Figure 1.6) and tertiary (Figure 1.7) education changed by year of birth, after controlling for district fixed effects and a district-specific trend. The top panels correspond to the coefficients for each cohort, separately for those born in high-goiter and non-high-goiter districts, whereas the bottom panels show the difference between high- and non-high-goiter districts for each cohort-specific coefficient. It is hard to discern a break in the trends on the top panels, but it is easier from the bottom panels to see that something changed for those born after 1922 in high-goiter districts. Whereas there was a converging trend between the two district groups prior to 1922, this trend seems to have stalled or reversed after 1922.

This departure from trend becomes even more apparent when one looks at males and females separately. Figures 1.8 and 1.9 show the regression-adjusted difference in coefficients between high- and non-high-goiter districts for secondary (Figure 1.8) and tertiary education (Figure 1.9), by gender. In the case of secondary education, for both males and females, there is a clear departure from trend starting around 1922, which coincides with the launch of the iodization campaign, and which continues as iodized salt spread around the country. For tertiary education, males do not seem affected, but for females there is, again, a change in the trend right around 1922.

Table 1.3 shows results of the regression-equivalent of the above graphs, first for the sample as a whole, and then separately by gender. I look at all cohorts, but also at a smaller age range, those born in 1910-1935. More specifically, I run the following regression for an individual $i$ born in district $d$ in year $y$:

$outcome_{idy} = \alpha + \beta \cdot$ *1 (Born in high-goiter district) X 1 (Born after 1922)*

+ *District of birth Fixed Effects*

+ *District of birth time trend*

+ *Cohort of Birth Fixed Effects* $+\epsilon_{idy}$

The outcomes which I look at are graduation from secondary- and tertiary-level education. The coefficient of interest is $\beta$. District of birth fixed effects take away the effect of any omitted district-specific, time-invariant characteristics, which might affect an individual's education. Cohort fixed effects control for any unobservable, country-wide characteristics that are common to each cohort in my sample. Finally, a district-specific linear time trend removes the effect of factors which change gradually over time and might affect the educational outcomes of cohorts born in a given district. Such factors include, for example, better access to educational opportunities over time, improving general health conditions, and ever-lowering transportation and communication costs. The coefficient $\beta$ will capture the departure of educational outcomes from this trend for those born in high-goiter districts after 1922. Standard errors are clustered at the district-cohort level.

It is evident from Table 1.3 that there was a departure from trend for high-goiter districts in 1922. Whether we look at all cohorts, or only at the cohorts born closer to 1922, the probability of graduating from secondary education increases by between 1 and 1.6 percentage points, whereas

Table 1.3: Salt sales and education: Coefficient on high-goiter dummy X Born after 1922 dummy

| | | |
|---|---|---|
| | | WHOLE SAMPLE |
| | All cohorts | Born 1910-1935 |
| Secondary Education | 1.59166*** | 1.04939*** |
| | (0.35161) | (0.38659) |
| Number of Observations | 3086287 | 1435764 |
| R-squared | 0.0923 | 0.073 |
| Tertiary Education | 0.40358** | 0.47352* |
| | (0.19633) | (0.25965) |
| Number of Observations | 3086287 | 1435764 |
| R-squared | 0.0305 | 0.0186 |
| | | MALES ONLY |
| | All cohorts | Born 1910-1935 |
| Secondary Education | 0.27304 | 0.50586 |
| | (0.37112) | (0.49232) |
| Number of Observations | 1503257 | 721813 |
| R-squared | 0.0862 | 0.0722 |
| Tertiary Education | 0.09915 | 0.16217 |
| | (0.29536) | (0.38939) |
| Number of Observations | 1503257 | 721813 |
| R-squared | 0.0319 | 0.0221 |
| | | FEMALES ONLY |
| | All cohorts | Born 1910-1935 |
| Secondary Education | 2.75442*** | 1.29066** |
| | (0.47548) | (0.52914) |
| Number of Observations | 1583030 | 713951 |
| R-squared | 0.1145 | 0.095 |
| Tertiary Education | 0.64007*** | 0.70804** |
| | (0.23198) | (0.30726) |
| Number of Observations | 1583030 | 713951 |
| R-squared | 0.0345 | 0.0172 |

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%

Coefficients correspond to changes in percentage points.

High-goiter districts are those belonging to the top 25% of the population-weighted goiter distribution.

All regressions include district of birth and cohort fixed effects, as well as a district-specific trend.

Standard errors in parentheses, clustered at the district-year of birth level.

the effect is smaller for the probability of graduating from tertiary education, which is a little more than 0.4 percentage points.

When we look into each gender separately, it becomes clear that these effects are driven by females. For women born after 1922 in high-goiter districts, the probability of graduating from secondary-level education increases by 2.7 percentage points. This is a big change; according to Table 1.2, the percentage of women graduating from secondary education increased by 17.07 percentage points for those born after 1922 compared to earlier cohorts. The coefficient on secondary education for women indicates that almost one-sixth or 16% of this change was due to iodization.

The change in probability for tertiary education is, again, much smaller, around 0.65 percentage points. Given that tertiary education graduation rates for women born in high-goiter districts increased by 8.61 percentage points over this period, the contribution of iodization corresponds roughly to 7% of the total change in graduation rates.

When we limit the sample to women born in 1910-1935, the effect on secondary education falls by more than half, which is puzzling. This drop in the coefficient might be related to the actual penetration of iodized salt in high-goiter districts, which occurred later in time, and therefore affected younger cohorts, who were born after 1935. This possibility is explored in section 1.8.

## 1.8 A second look at the data: The penetration of iodized salt in each canton

### 1.8.1 A closer look into cantonal iodized salt sales

As manifested by the decrease in deaf-mutism rates described in section 1.6, the campaign for iodization had strong and immediate effects on the population. The graphs and regression results in section 1.7 also suggest that high-goiter regions were exposed to some kind of treatment which affected the education of cohorts born around the time of iodization.

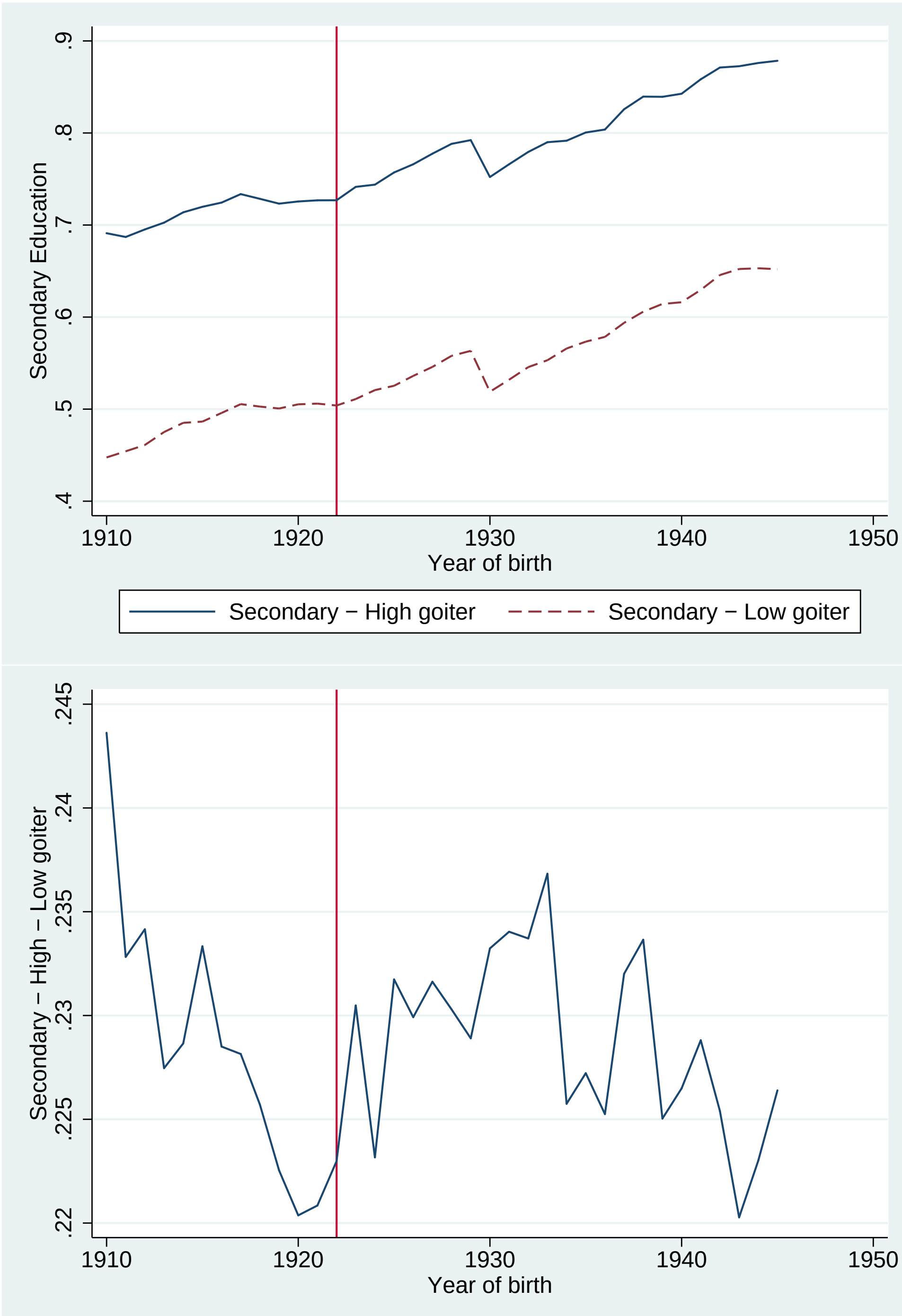
However, a closer look into the data paints a more complex picture. It seems that high-goiter cantons introduced iodized salt later than the rest of the country. Table 1A-1 in the Appendix contains annual, canton-level data of iodized salt sales as a percentage of total salt sales for the period 1922-1949[22]. The data in Table 1A-1 come from a paper published in 1962 by H. J. Wespi[23] (Wespi 1962). Table 1A-2 shows population-weighted goiter rates using Bircher's data, aggregated at the canton level (Bircher 1883). A quick look at Tables 1A-1 and 1A-2 shows that high-goiter cantons tended to introduce iodized salt later than the rest of the country.

Table 1A-1 shows how widespread the use of the "new salt" was at each point in time. It shows that for most cantons the transition to iodized salt was fast, whereas for others it came more

[22] Jura was not yet a canton at that time, so it is not part of Table 1A-1. What later became the canton of Jura was still part of the canton of Bern at that time.

[23] M.D. and Chief Doctor of Women's Clinic in Aarau. Incidentally, H.J. Wespi was the son-in-law of H. Eggenberger, the doctor who first introduced iodized salt in Appenzell-Ausserrhoden in 1922. I am grateful to Prof. Dr. Hans Bürgi for providing me with H. J. Wespi's paper, which contained these data.

Figure 1.6: Secondary education, difference between high-and low goiter districts




source: *Bircher (1883) and 1970 Swiss Census*

Figure 1.7: Tertiary education, difference between high-and low goiter districts


source: *Bircher (1883) and 1970 Swiss Census*

Figure 1.8: Secondary education, males and females, difference between high-and low goiter districts

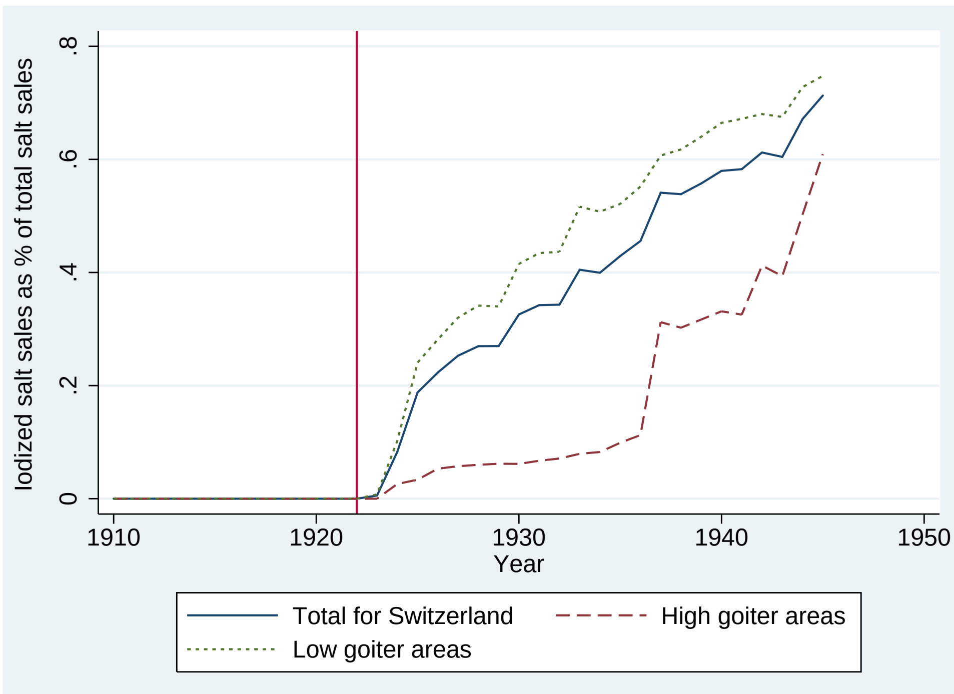

source: *Bircher (1883) and 1970 Swiss Census*

Figure 1.9: Tertiary education, males and females, difference between high-and low goiter districts


source: *Bircher (1883) and 1970 Swiss Census*

gradually. Examples of a fast transition are Schwyz, Luzern and Genève, whereas the transition was more gradual in Thurgau and Graubünden. The data also indicate that the timing of adoption of iodized salt differed across cantons; some cantons, such as Nidwalden and Schaffhausen, iodized early, whereas others, such as Aargau, Basel-Stadt and Basel-Land, were much slower in their adoption. Figure 1.1 shows that the adoption of the "new salt" for country as a whole was gradual.

Figure 1.10: Iodized salt penetration in high- and low-goiter districts




source: *Bircher (1883), Wespi (1962) and 1970 Swiss Census*

Figure 1.10 confirms that high-goiter districts belonged to a large extent to cantons which iodized relatively late. Figure 1.10 is similar to Figure 1.1 in that it shows population-weighted averages of iodized salt sales, but apart from showing the countrywide average, Figure 1.10 also breaks the sample down into high-goiter districts and the rest of the country. High-goiter districts, which seem to have benefited from iodization immediately after 1922, actually lagged behind in the introduction of iodized salt; there is one big increase around 1936, and another one after 1942. The sudden increase in iodized salt availability in high-goiter districts in 1936 is driven by the jump in iodized salt sales in the canton of Bern, which went from 11% in 1935 to 54% in 1936. Bern, as shown in Table 1A-2, was among the most populous and worst-afflicted cantons, so a jump in iodized salt sales there would have a significant impact for the country-wide average. Similarly, the second big increase shown in Figure 1.10 and taking place after 1940 corresponds to jumps in iodized salt sales in the cantons of Luzern and Fribourg, which were also populous and had highly-afflicted districts.

It is unclear why high-goiter cantons lagged disproportionately in the introduction of iodized salt in their markets. One possible explanation is that iodized salt and iodine supplementation in general was regarded with some suspicion in the initial stages of their introduction, because they were linked to a spike in thyroid-related deaths. Indeed, a sudden, uncontrolled increase in iodine intake in individuals who have been chronically exposed to iodine deficiency can cause the thyroid gland to produce excessive amounts of thyroid hormone, leading to thyrotoxicosis, which might be fatal. Feyrer, Politi and Weil (2008) have documented a significant spike of thyroid-related deaths in the USA following the introduction of iodized salt in 1924. These deaths, as expected, were concentrated on older age groups, which were exposed to iodine deficiency over a longer time.

Taking one more look at the graphs in section 1.7, there is some subtle indication of further departures from trend for high-goiter districts in the late 1930's and early 1940's. For example, in Figures 1.7 and 1.9, the differences in regression-adjusted probabilities of graduating from tertiary education between high-goiter districts and the rest of the country seem to increase after 1935. At any rate, iodized salt penetration for each canton deserves closer attention, and incorporating this extra piece of information into the analysis the next logical step.

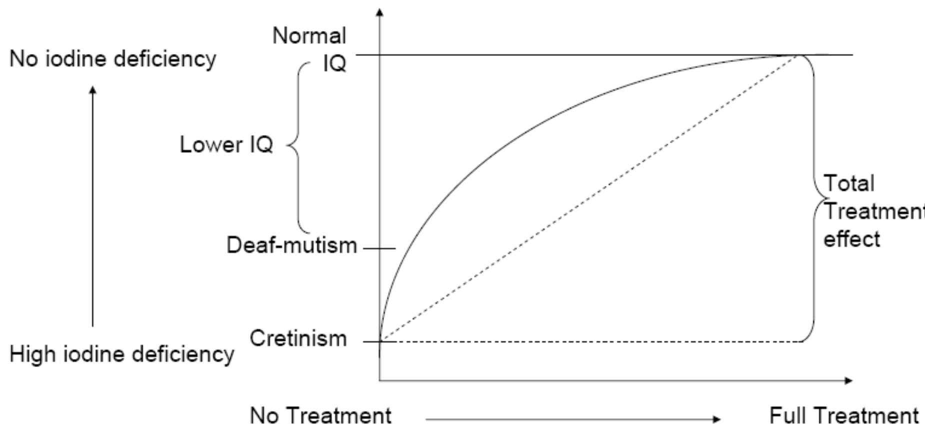
### 1.8.2 An iodine response function

The fact that iodization seems to have had immediate effects in high-goiter areas goes contrary to the fact that these areas were, in fact, those which iodized in later years. To reconciliate these two views, it is possible to imagine that the outcomes of treatment are non-linear; in particular, it might be easier to cure acute conditions and correct sharp outcomes such as cretinism and deaf-mutism with low levels of iodine supplementation, whereas more subtle outcomes, such as school graduation rates, might require a more complete and universal degree of treatment. High-goiter cantons were exposed to a first shock in 1922, which had to do with increased information and awareness of the prophylactic uses of iodine. Complete, universal treatment came later, when iodized salt was introduced in these areas.

Such a model is graphically depicted in Figure 1.11. The vertical axis corresponds to the level of iodine deficiency in a locality, and the horizontal axis to the degree of iodine treatment. Non-goitrous areas are located on the upper right part of the graph, and increased iodine availability will not increase average IQ in their population. A high-goiter area with endemic goiter and cretinism, on the other hand, would be on the lower left part, and would benefit from increased iodine intake. As iodine supplementation becomes widespread, the high-goiter area will become less and less deficient, and once treatment is complete, it will reach the upper right part of the graph. The adjustment, though, doesn't have to be linear in terms of the impact of iodization on cognitive outcomes. According to this model, it will be relatively easy to cure cretinism and deaf-mutism with low doses of iodine, but it will be harder and it will take higher levels of treatment to restore the population's cognitive ability to normal levels. Education levels will be mostly affected once treatment brings an area to the flatter part of the curve.

High-goiter districts may have had a delay in the provision of iodized salt, but they were most likely subject to some degree of treatment in 1922. Iodized salt is by far the easiest, but it is not the

Figure 1.11: Iodine response function




only way to provide iodine to a population. As medical knowledge and awareness of the prophylactic use of iodine in Switzerland grew, it is possible that partial treatment took place after 1922, even in areas where iodized salt per se was not available. For example, doctors might have prescribed iodine supplements to pregnant women who developed goiters. This is consistent with finding a treatment effect just by looking at post-1922 outcomes, especially for such acute conditions as cretinism and deaf-mutism. According to the model, though, a higher level of treatment, such as widespread use of iodized salt, will affect more subtle outcomes, such as school graduation rates. The next step, therefore, is to incorporate the data on iodized salt sales as part of the analysis[24].

### 1.8.3 Using iodized salt sales to identify the effect of iodization

In a second specification, I introduce iodized salt sales at the canton level directly as a regressor in a linear probability model of graduating from secondary and tertiary education. In particular, I control for the percentage of iodized salt sales in total salt sales one year prior to birth in one's canton of birth. I also control for canton and cohort fixed effects, to remove the effect of any omitted variables that are canton- or cohort-specific. In addition, I introduce a canton time trend, to control for any other gradual changes that might have affected one's schooling outcomes. In short, I run the following regression for an individual $i$ born in canton $c$ in year $y$:
$outcome_{idy} = \alpha + \beta \cdot$ *Iodized salt 1 year prior to birth*

[24]It is possible that within a geographic location, selection into treatment during the first phase of iodization was non-random. For example, access to information about the benefits of iodine supplementation for pregnant women may have been correlated with one's socioeconomic status. In this case, the break in trend for high-goiter areas which I'm observing in 1922 comes from a limited part of the population distribution. Non-random selection into treatment is less of an issue in later stages, when iodized salt was widely used.

Table 1.4: Salt sales and education: Coefficient on Iodized Salt 1 year prior to birth

| | WHOLE SAMPLE | | |
|---|---|---|---|
| | ALL AREAS | HIGH-GOITER | LOW-GOITER |
| Secondary Education | -0.1561 | 1.51967*** | -0.34064 |
| | (0.37471) | (0.52923) | (0.52798) |
| Number of Observations | 3078907 | 768353 | 756364 |
| R-squared | 0.0708 | 0.0602 | 0.0745 |
| Tertiary Education | 0.49531** | 1.91756*** | 0.86382** |
| | (0.23577) | (0.48028) | (0.40792) |
| Number of Observations | 3078907 | 768353 | 756364 |
| R-squared | 0.0263 | 0.0259 | 0.0364 |
| | MALES ONLY | | |
| | ALL AREAS | HIGH-GOITER | LOW-GOITER |
| Secondary Education | -0.04116 | 0.91858 | 0.21011 |
| | (0.36863) | (0.66006) | (0.56328) |
| Number of Observations | 1499495 | 375772 | 367747 |
| R-squared | 0.0654 | 0.0583 | 0.0653 |
| Tertiary Education | 0.39761 | 1.811** | 1.65157*** |
| | (0.33792) | (0.72043) | (0.52504) |
| Number of Observations | 1499495 | 375772 | 367747 |
| R-squared | 0.0265 | 0.0242 | 0.0379 |
| | FEMALES ONLY | | |
| | ALL AREAS | HIGH-GOITER | LOW-GOITER |
| Secondary Education | -0.53394 | 1.94846*** | -1.04845 |
| | (0.46747) | (0.68709) | (0.68117) |
| Number of Observations | 1579412 | 392581 | 388617 |
| R-squared | 0.0851 | 0.0688 | 0.097 |
| Tertiary Education | 0.56445** | 2.04099*** | 0.05975 |
| | (0.24226) | (0.46669) | (0.42236) |
| Number of Observations | 1579412 | 392581 | 388617 |
| R-squared | 0.0307 | 0.033 | 0.0385 |

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%
Coefficients correspond to changes in percentage points.
High-goiter districts are those belonging to the top 25% of the population-weighted goiter distribution.
Low-goiter districts are those belonging to the bottom 25% of the population-weighted goiter distribution.
All regressions include canton of birth and cohort fixed effects, as well as a canton-specific trend.
Standard errors in parentheses, clustered at the canton-year of birth level.

+ *Canton of birth Fixed Effects*
+ *Canton of birth time trend*
+ *Cohort of Birth Fixed Effects* $+\epsilon_{idy}$,

where $outcome_{idy}$ is an indicator variable for having graduated from secondary/tertiary education, and standard errors are clustered at the canton-cohort level.

Results from this regression are shown on Table 1.4. As shown in this table, iodized salt doesn't seem to have had much of an effect for the county as a whole, but breaking the sample into high- and low- goiter districts tells a different story. High-goiter districts are those corresponding to the top 25% of the population-weighted goiter distribution, whereas low-goiter districts are those corresponding to the bottom 25% of the same distribution. The probability of graduating from secondary and tertiary education if one was born in a high-goiter district after universal use of iodized salt increases by 1.5 and almost 2 percentage points, respectively. Again, this increase is largely driven by females. According to Table 1.4, the increase in the probability of graduating from tertiary-level education is higher than for secondary education. This is consistent with the notion that affecting secondary-level graduation rates might have been easier in the first stage of the intervention, which corresponds to increased awareness and the "informational shock" which occurred in 1922. However, once iodine prophylaxis became universal and complete with the advent of iodized salt, it affected "harder-to-achieve" outcomes, such as graduation from tertiary education.

## 1.9 Fuzzy regression discontinuity and jumps in sales of iodized salt

A closer look into the iodized salt sales data reveals that the transition to iodized salt happened pretty rapidly for most cantons. For example, Luzern went from 5% to 54% to 100% of total salt sales being iodized in a period of only two years, from 1942 to 1944. I take advantage of such sudden jumps in iodized salt sales, as they correspond to jumps in the probability of being treated. Since these jumps all occurred in a small window of time, this method is "cleaner" than a simple regression of outcomes on iodized salt sales, as there are fewer possible confounding effects taking place within same small time frame in a particular canton.

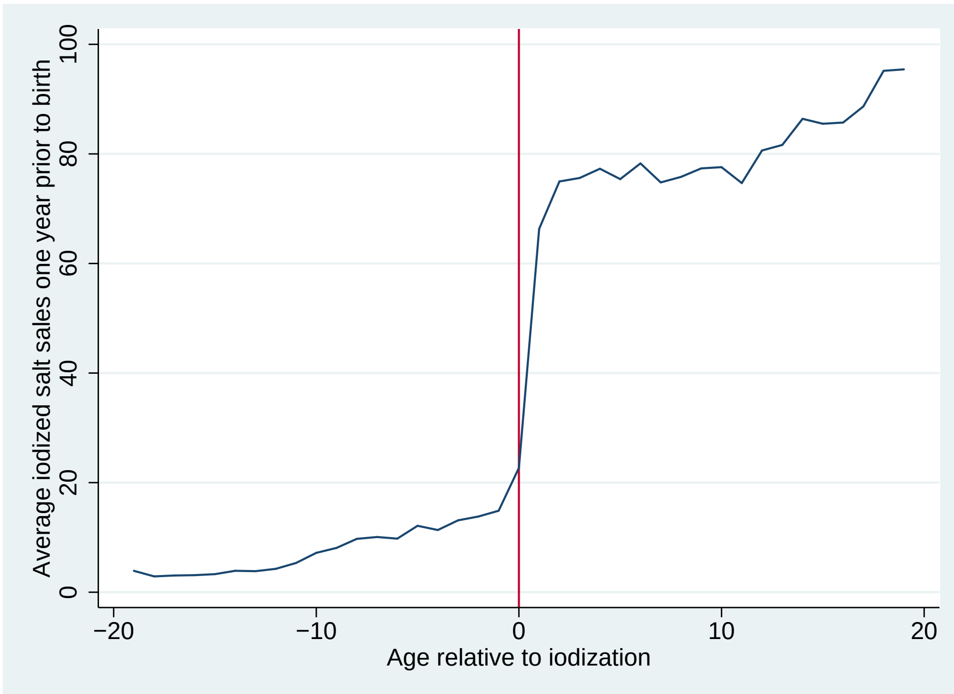
Based on the year of the jump in iodized salt sales, which is particular to each canton, I construct a new variable, "age relative to iodization", which is common across all people born in the same canton in the same year, but will generally be different across cohorts born in different cantons. Figure 1.12 shows the population-weighted average percentage of iodized salt sales one year prior to birth, plotted against age relative to iodization. At relative age 0, iodized salt sales jump from around 22% to around 66%.

I check for some preliminary evidence of how being born in a high-goiter district right after a jump in iodized salt sales affects one's educational achievement. Table 1.5 shows results of a regression of educational outcomes of an indicator variable equal to 1 if someone was born in a high-goiter district after a jump in iodized salt sales, controlling for district and cohort of birth fixed effects, as well as a district-specific time trend. I run the following regression for an individual $i$ born in district $d$ in year $y$:

$outcome_{idy} = \alpha + \beta\cdot$ *1 (Born in high-goiter district) X 1 (Born after jump in sales of iodized salt)*
+ *District of birth Fixed Effects*
+ *District of birth time trend*
+ *Cohort of Birth Fixed Effects* $+\epsilon_{idy}$,

where outcomes are the probability of graduating from secondary and tertiary-level education, and where standard errors are clustered at the district-cohort level. First, I run the regression on the whole sample, and then for males and females separately. Also, I first use the whole sample and

Figure 1.12: Iodized salt sales by age relative to iodization




source: *Wespi (1962), and 1970 Swiss Census*

then only the sub-sample of those people born within ten years of the jump in iodized salt sales. In columns (1) and (3) of Table 1.5, I use cohort fixed effects that are common for high-goiter districts and the rest of the country, whereas in columns (2) and (4) I allow cohort fixed effects to be different for high-goiter districts.

According to Table 1.5, the probability of graduating from secondary education grew by between 0.8 and 1.2 percentage points for people born in high-goiter districts after a jump in iodized salt sales, whereas the same number for tertiary education ranges from 0.3 to 1.3 percentage points. When I use all cohorts in the sample, some statistical significance is lost when I don't constrain cohort fixed effects to be the same across high-goiter districts and the rest of the country. Results seem, again, to be driven by females, although the difference between male and female coefficients is not always statistically significant. When I limit the analysis to individuals born within a decade from iodization, results are no longer driven mainly by females. Also, there's a much smaller difference between the two specifications, and, if anything, coefficients are higher for the stricter specification of column (4) (although not statistically distinguishable from the coefficients in column (3)), where I allow cohort fixed effects to vary across the two types of districts (high-goiter and non-high-goiter). According to results in column (4), people born in high-goiter districts after a jump in iodized salt sales had a 1 percentage point higher probability of graduating from tertiary education. It is noteworthy that the magnitude of this coefficient is almost double of that suggested by the earlier,

Table 1.5: Coefficient on high-goiter dummy X Born after jump in iodized salt sales

| | | | | |
|---|---|---|---|---|
| | WHOLE SAMPLE | | | |
| | All cohorts | | Born +/- 10 years from jump | |
| | (1) | (2) | (3) | (4) |
| Secondary Education | 0.94485*** | 0.27477 | 0.81078** | 1.24831*** |
| | (0.29962) | (0.37762) | (0.35746) | (0.37397) |
| Number of Observations | 3086287 | 3086287 | 1080394 | 1080394 |
| R-squared | 0.0923 | 0.0924 | 0.0746 | 0.0747 |
| Tertiary Education | 1.28749*** | 1.04325*** | 0.74916** | 1.03269*** |
| | (0.21145) | (0.25326) | (0.29383) | (0.313990) |
| Number of Observations | 3086287 | 3086287 | 1080394 | 1080394 |
| R-squared | 0.0305 | 0.0305 | 0.0193 | 0.0193 |
| | MALES ONLY | | | |
| | All cohorts | | Born +/- 10 years from jump | |
| | (1) | (2) | (3) | (4) |
| Secondary Education | 0.44635 | 0.05057 | 0.97789** | 0.96029* |
| | (0.33153) | (0.44122) | (0.48179) | (0.50658) |
| Number of Observations | 1503257 | 1503257 | 544963 | 544963 |
| R-squared | 0.0862 | 0.0862 | 0.0719 | 0.072 |
| Tertiary Education | 0.46311 | 0.73809* | 0.75222 | 1.27428*** |
| | (0.31468) | (0.38552) | (0.45916) | (0.49252) |
| Number of Observations | 1503257 | 1503257 | 544963 | 544963 |
| R-squared | 0.0319 | 0.0319 | 0.0233 | 0.0233 |
| | FEMALES ONLY | | | |
| | All cohorts | | Born +/- 10 years from jump | |
| | (1) | (2) | (3) | (4) |
| Secondary Education | 1.11057*** | 0.41875 | 0.77607 | 1.73938*** |
| | (0.40643) | (0.52814) | (0.53812) | (0.56875) |
| | 1583030 | 1583030 | 535431 | 535431 |
| | 0.1145 | 0.1146 | 0.0958 | 0.0959 |
| Tertiary Education | 2.00584*** | 1.37774*** | 0.8172** | 0.9316** |
| | (0.26661) | (0.33157) | (0.41626) | (0.43615) |
| | 1583030 | 1583030 | 535431 | 535431 |
| | 0.0346 | 0.0346 | 0.0226 | 0.0226 |

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%

Coefficients correspond to changes in percentage points.

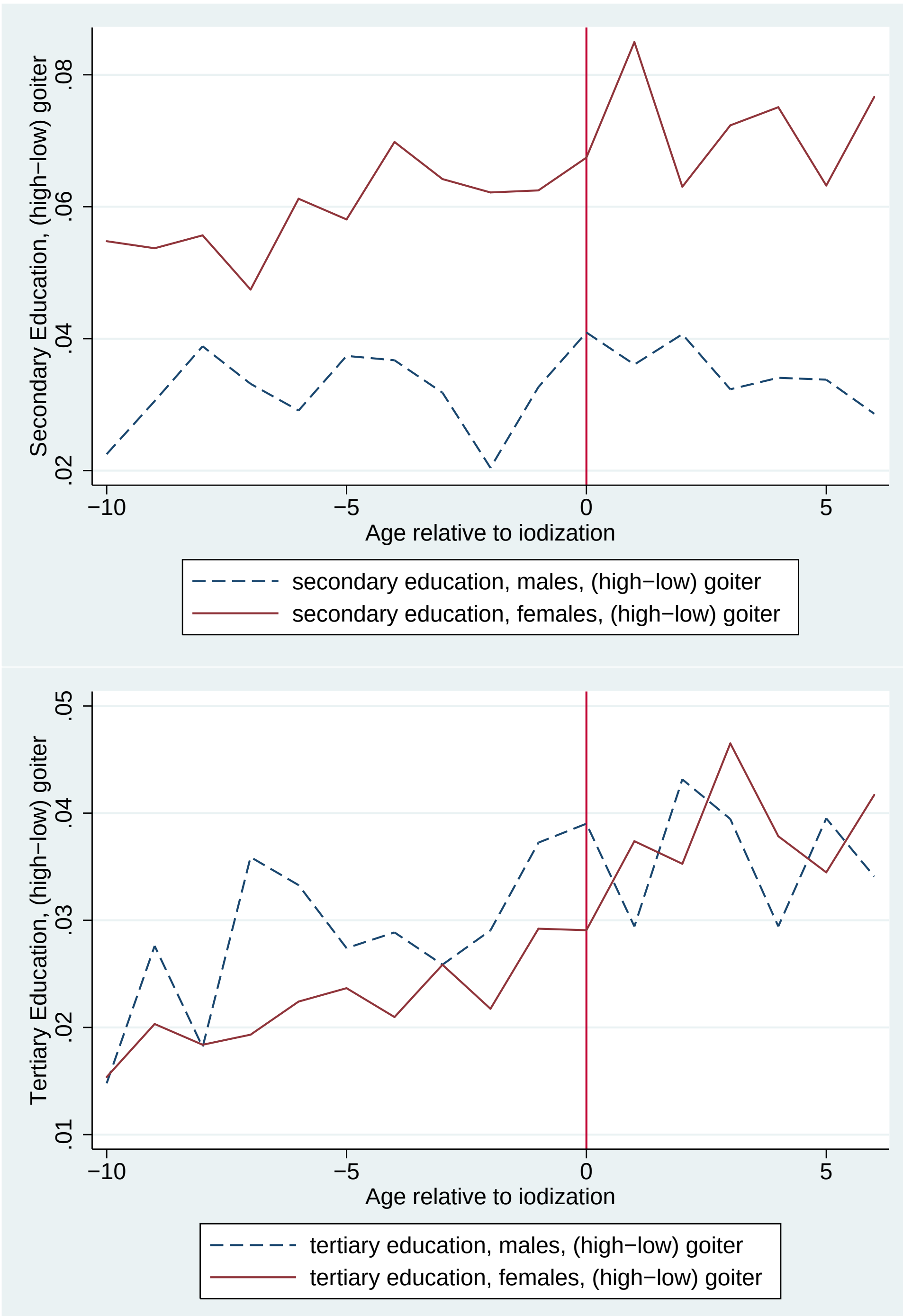
Columns (1) and (3) assume common cohort fixed effects for high- and non-high-goiter districts.

Columns (2) and (4) assume different cohort fixed effects for high- and non-high-goiter districts.

All regressions include canton of birth and cohort fixed effects, as well as a canton-specific trend.

Standard errors in parentheses, clustered at the district-year of birth level.

Figure 1.13: Secondary and Tertiary education before and after jump in iodized salt sales, difference between high-and low goiter districts




source: *Bircher (1883), Wespi (1962), and 1970 Swiss Census* preliminary results of Table 1.3.

Figure 1.13 is a graphical representation of the results shown in Table 1.5. It is a regression-adjusted plot showing how the difference in probability of graduating from secondary (top panel) and tertiary (bottom panel) education between those born in high-goiter districts and the rest of the country changed according to one's age relative to the jump in sales of iodized salt, for males and females separately. The effect is barely there for males, but for females the difference clearly increased for those born around the jump in iodized salt sales.

The probability of someone being treated with adequate iodine in utero increases discontinuously if they were born after the jump in sales. This observation provides the framework for a fuzzy regression discontinuity (FRD) design (for a description of FRD see, for example, Imbens and Lemieux (2008)). Using jumps in iodized salt sales, I identify the effect of iodization on educational outcomes. My identification relies on the fact that not all cantons iodized at the same time. Because of the difference in the timing of intervention, I can control for unobserved, time-invariant canton characteristics, as well as unobserved, space-invariant cohort characteristics. I regress indicator variables for having graduated from secondary and tertiary education on the percentage of iodized salt sales (at the canton-level) one year prior to birth (and additional controls), but I instrument iodized salt sales with an indicator variable equal to 1 if someone is born after the big jump in sales which marked each canton's decisive transition to iodized salt. I run the following regression for an individual $i$ born in canton $c$ in year $y$:

$outcome_{idy} = \alpha + \beta \cdot$ *Iodized salt 1 year prior to birth*
\+ *Trend before jump in iodized salt sales*
\+ *Trend after jump in iodized salt sales*
\+ *Canton of birth Fixed Effects*
\+ *Canton of birth time trend*
\+ *Cohort of Birth Fixed Effects* $+\epsilon_{idy}$,

where $outcome_{idy}$ is an indicator variable for having graduated from secondary/tertiary education, and standard errors are clustered at the canton-cohort level. I include both a linear canton-specific time trend, but also linear nationwide trends which are allowed to differ before and after the jump in iodized salt sales.

Estimation results are shown in Table 1.6. First, I estimate the effects for the whole sample and all areas, and then I use only those observations corresponding to the top and bottom 25% of the population-weighted goiter distribution, and estimate the effects of iodization separately for each of these two parts of the distribution. Then I estimate effects for males and females separately, using the same cuts of the data.

Results using the fuzzy regression discontinuity design suggest even stronger effects for high-goiter areas than previous specifications, and they show the contrast between the effect estimated for high-and low-goiter districts. For those born in high-goiter districts, there is a 2.1 percentage point increase in the probability of graduating from secondary education, and a 1.4 percentage point increase for tertiary education. Females benefited more in the case of secondary education, where

Table 1.6: Fuzzy Regression Discontinuity: Coefficient on Iodized Salt 1 year prior to birth

| | WHOLE SAMPLE | | |
|---|---|---|---|
| | ALL AREAS | HIGH-GOITER | LOW-GOITER |
| Secondary Education | -1.51933*** | 2.11722*** | -1.03942** |
| | (0.42756) | (0.5057) | (0.51821) |
| Number of Observations | 3078907 | 768353 | 756364 |
| R-squared | 0.0708 | 0.0603 | 0.0745 |
| Tertiary Education | 0.01346 | 1.43328*** | 0.28196 |
| | (0.27196) | (0.52231) | (0.41398) |
| Number of Observations | 3078907 | 768353 | 756364 |
| R-squared | 0.0264 | 0.026 | 0.0364 |
| | MALES ONLY | | |
| | ALL AREAS | HIGH-GOITER | LOW-GOITER |
| Secondary Education | -1.12351*** | 1.26888* | -0.12438 |
| | (0.41737) | (0.74509) | (0.60595) |
| Number of Observations | 1499195 | 375772 | 367747 |
| R-squared | 0.0655 | 0.0584 | 0.0653 |
| Tertiary Education | -0.45101 | 1.66566** | 0.86472 |
| | (0.37484) | (0.7503) | (0.54564) |
| Number of Observations | 1499195 | 375772 | 367747 |
| R-squared | 0.0265 | 0.0246 | 0.038 |
| | FEMALES ONLY | | |
| | ALL AREAS | HIGH-GOITER | LOW-GOITER |
| Secondary Education | -1.95353*** | 3.48568*** | -2.14152*** |
| | (0.56893) | (0.83893) | (0.68567) |
| Number of Observations | 1579412 | 392581 | 388617 |
| R-squared | 0.0852 | 0.0689 | 0.097 |
| Tertiary Education | 0.46896 | 1.55792** | -0.2541 |
| | (0.29641) | (0.63083) | (0.45283) |
| Number of Observations | 1579412 | 392581 | 388617 |
| R-squared | 0.0307 | 0.0331 | 0.0385 |

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%
Coefficients correspond to changes in percentage points.
High-goiter districts are those belonging to the top 25% of the population-weighted goiter distribution.
Low-goiter districts are those belonging to the bottom 25% of the population-weighted goiter distribution.
All regressions include canton of birth and cohort fixed effects, as well as a canton-specific trend.
Standard errors in parentheses, clustered at the canton-year of birth level.

their probability of graduation increased by 3.5 percentage points.

Interestingly, the sample as a whole experienced a decline in the probability of graduation from secondary education, which is clearly driven by people born in districts belonging to the middle and lower parts of the goiter distribution. The magnitude of this decline is smaller than the magnitude of the increase in graduation rates in high-goiter regions, and it could be explained by the presence of short-run constraints in the supply of secondary education. Secondary education was much less widespread in the 1920's than it is today, and only a little over 50% of the population in my sample graduated from it, so supply constraints might have been important. If capacity constraints are behind the negative effect of iodization for the middle and lower parts of the goiter distribution, however, they don't seem to matter much in the case of tertiary education. Iodization had a significant impact on the probability of graduating from tertiary education for high-goiter districts, but it didn't affect tertiary education in other regions.

## 1.10 Interpretation of coefficients

There is strong evidence that iodine provision in previously deficient regions had a significant impact on the educational attainment of cohorts exposed to it. Looking across the specifications outlined in previous sections, the probability of graduating from secondary education increased by around 1.1 percentage points, whereas the same number for tertiary education is around 1 percentage point. Given that secondary school graduation rates increased by about 15 percentage points for those born after 1922 compared to those born before 1922 in high-goiter districts, iodization alone contributed about 7.3% of that change. If tertiary education increased by 1 percentage point, then, given that the change in graduation rates between those born before and after 1922 in high-goiter districts was 8.5 percentage points, iodization is responsible for about 12% of the total change in graduation rates from tertiary education in high-goiter districts.

Results are very strong for females. Female graduation rates increased by around 1.5 percentage points for secondary education, and by about 1.2 percentage points for tertiary education, thus accounting for 9% and 14% of the total change in female graduation rates in high-goiter regions respectively. Also, the effect of iodization is often statistically higher for females than for males. This result is consistent with two hypotheses: first, iodine deficiency might affect females more than males, so correcting it will have larger effects for the female population. Second, schooling outcomes across the two genders might be affected differently by a given increase in cognitive ability.

The first hypothesis is consistent with some evidence showing women to be more susceptible to thyroid-related disorders. According to the American Society for Clinical Endocrinologists, "more than 8 out of 10 patients with thyroid disease are women", and "women are five to eight times more likely than men to suffer from hypothyroidism"[25]. Feyrer et al. (2008) note that there was a large gender disparity in thyroid-related deaths following salt iodization in the USA. In particular, thyroid-related death rates were almost seven times higher for women than for men in 1926 (1.1

[25]Source: http://www.aace.com/public/awareness/tam/2005/pdfs/thyroid_disease_fact_sheet.pdf

per 100,000 for men, versus 7 per 100,000 for women). My findings are consistent with cross-gender differences in the effects of iodine deficiency on brain development in utero. A correction of iodine deficiency in utero would, under such circumstances, affect females more than males, and therefore have a bigger effect on the schooling outcomes of females once the exposed cohorts reach schooling age.

However, there is a competing hypothesis which is consistent with my findings. A household's response to a given increase in the cognitive ability of its offspring could be different across genders. In particular, household decisions regarding the schooling levels of its children could be more sensitive to cognition for girls than for boys. In such a case, even though male and female fetuses are equally affected by iodine deficiency in utero, a given increase in cognitive ability will produce different effects on schooling outcomes across genders.

The effect on educational outcomes identified in the previous sections of this paper arises from increased health capital in utero and early life. Health investments at such an early stage have been shown to have a significant impact later in one's lifetime, but I cannot distinguish whether this effect comes from increased innate cognitive ability alone, better treatment at home and school (before even reaching upper-secondary and tertiary levels of education), or a combination of the two. It is possible, for example, that a smarter cohort received different parental and teacher attention in childhood and early adolescence, in which case the initial effect of iodization was magnified by responses coming from one's social environment, which increased their potential for higher educational attainment even more than the initial improvement in cognitive ability.

## 1.11 Concluding remarks

The treatment of iodine deficiency in Switzerland provides us with a rare opportunity to examine how an exogenous increase in the cognitive ability of a population translates into higher schooling. It also shows that there can be important differences across genders on how large-scale public health interventions of this kind translate into economically significant outcomes. Although I cannot distinguish whether this is due to physiological gender differences or to differential environmental responses for males and females from the part of the household and general social context in which one grows up, the fact that female education was more affected than male education is something to keep in mind when thinking about current efforts to eradicate iodine deficiency, and thereby increase schooling and productivity in much of the developing world.

The potential non-linearity of treatment is also noteworthy. While low levels of treatment might cure acute conditions, such as cretinism and deaf-mutism, it takes a well-orchestrated public health campaign to affect more subtle outcomes, such as schooling and graduation levels. This is important when evaluating public health campaigns; the outcomes one chooses to look at might be important when deciding on the success of an intervention.

A cost-benefit analysis is beside the point here; iodized salt was clearly cost-effective, even if one only considers the reduction in medical costs related to goiters and other iodine-related disorders, let alone factoring in the benefits of increased cognition and productivity. Prof. Dr. Hans Bürgi estimates that, had it not been for iodine prophylaxis, the cost of homes providing for cretins and the medical bills related to iodine deficiency disorders would have been around 270 million 2005 Swiss Francs. The cost of adding iodine to salt, on the other hand, amounted to a total of 1.4 million Swiss Francs in 2005[26].

The late 1990s saw significant improvements in iodized salt availability in the world, and UNICEF estimates that 70% of people in the world consumed iodized salt in 2000, whereas less than 20% did so back in 1990. However, iodine deficiency remains the single most easily preventable cause of mental retardation today, and 38 million children are born annually at the risk of developing iodine deficiency disorders (UNICEF 2008). The historical experience of Switzerland can serve as a paradigm for countries fighting with iodine deficiency.

[26]Personal communication to the author.

# 1.A Appendix

Table 1A-1: Annual iodized salt sales as a percentage of total salt sales

| | Year | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Canton Name | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 |
| Zürich | | 18 | 21 | 18 | 18 | 18 | 17 | 15 | 13 | 14 | 53 | 51 | 53 | 54 |
| Bern | | 1 | 1 | 4 | 4 | 4 | 4 | 5 | 6 | 6 | 6 | 7 | 8 | 11 |
| Luzern | | 5 | 3 | 4 | 6 | 6 | 6 | 7 | 7 | 8 | 6 | 8 | 8 | 8 |
| Uri | | | | | | | | 100 | 100 | 97 | 97 | 97 | 93 | 88 |
| Schwyz | | | 1 | 1 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Nidwalden | | 47 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Obwalden | | 7 | 8 | 8 | 50 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Glarus | | 4 | 83 | 37 | 27 | 37 | 33 | 41 | 60 | 66 | 67 | 68 | 70 | 72 |
| Zug | | 23 | 26 | 81 | 97 | 88 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Fribourg | | | | 2 | 2 | 2 | 3 | 2 | 2 | 1 | 3 | 3 | ? | ? |
| Solothurn | | 1 | 2 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Basel-Stadt | | 5 | 10 | 12 | 12 | 13 | 14 | 15 | 14 | 13 | 14 | 14 | 10 | 10 |
| Basel-Land | | 2 | 5 | 5 | 11 | 12 | 9 | 10 | 34 | 15 | 14 | 14 | 12 | 28 |
| Schaffhausen | | 4 | 3 | 11 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 96 | 100 | 100 |
| Ap. Ausserrhoden | 43 | 55 | 75 | 75 | 67 | 67 | 67 | 73 | 74 | 70 | 77 | 67 | 68 | 69 |
| Ap. Innerrhoden | | 34 | 50 | 50 | 48 | 46 | 53 | 54 | 49 | 51 | 51 | 53 | 39 | 59 |
| St. Gallen | | 12 | 24 | 27 | 25 | 26 | 27 | 47 | 52 | 51 | 58 | 55 | 54 | 64 |
| Graubünden | | 3 | 6 | 9 | 9 | 13 | 16 | 18 | 17 | 20 | 22 | 21 | 20 | 21 |
| Aargau | | 4 | 9 | 11 | 11 | 12 | 12 | 10 | 11 | 13 | 12 | 9 | 10 | 9 |
| Thurgau | | 27 | 36 | 39 | 35 | 34 | 35 | 36 | 32 | 34 | 37 | 35 | 37 | 35 |
| Ticino | | | | | | | | 100 | 100 | 98 | 100 | 100 | 100 | 100 |
| Vaud | | 25 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Valais | | | 33 | 63 | 65 | 75 | 78 | 80 | 87 | 95 | 96 | 100 | 100 | 100 |
| Neuchâtel | | | 15 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 |
| Genève | | | | | | 1 | 1 | 1 | 2 | 3 | 4 | 3 | 27 | 66 |
| Switzerland | | 8 | 16 | 22 | 26 | 29 | 27 | 30 | 34 | 33 | 39 | 38 | 40 | 40 |

| | Year | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Canton Name | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 |
| Zürich | 52 | 53 | 52 | 53 | 55 | 55 | 48 | 63 | 67 | 70 | 70 | 70 | 77 | 77 |
| Bern | 54 | 64 | 65 | 66 | 63 | 73 | 69 | 71 | 71 | 73 | 69 | 74 | 73 | 75 |
| Luzern | 8 | 9 | 7 | 8 | 8 | 6 | 5 | 54 | 100 | 81 | 92 | 97 | 100 | 100 |
| Uri | 79 | 90 | 90 | 88 | 90 | 87 | 88 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Schwyz | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Nidwalden | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Obwalden | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Glarus | 73 | 76 | 76 | 81 | 82 | 87 | 92 | 94 | 93 | 94 | 93 | 94 | 95 | 97 |
| Zug | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Fribourg | ? | 3 | 3 | 4 | 7 | 39 | 31 | 36 | 50 | 76 | 76 | 100 | 100 | 100 |
| Solothurn | 4 | 4 | 54 | 74 | 69 | 58 | 62 | 65 | 66 | 67 | 64 | 63 | 60 | 58 |
| Basel-Stadt | 14 | 13 | 15 | 23 | 25 | 23 | 25 | 28 | 28 | 28 | 29 | 27 | 27 | 27 |
| Basel-Land | 16 | 15 | 15 | 18 | 17 | 17 | 18 | 18 | 18 | 19 | 18 | 20 | 21 | 21 |
| Schaffhausen | 100 | 100 | 100 | 100 | 100 | 97 | 95 | 100 | 100 | 100 | 100 | 97 | 96 | 100 |
| Ap. Ausserrhoden | 71 | 71 | 71 | 71 | 68 | 71 | 70 | 74 | 74 | 77 | 79 | 87 | 89 | 92 |
| Ap. Innerrhoden | 64 | 64 | 60 | 62 | 57 | 59 | 56 | 44 | 48 | 49 | 86 | 100 | 100 | 100 |
| St. Gallen | 69 | 68 | 68 | 68 | 67 | 59 | 67 | 78 | 88 | 89 | 91 | 91 | 93 | 93 |
| Graubünden | 24 | 24 | 26 | 43 | 75 | 85 | 86 | 94 | 94 | 93 | 93 | 96 | 94 | 95 |
| Aargau | 11 | 11 | 10 | 10 | 8 | 7 | 14 | 8 | 7 | 7 | 7 | 8 | 7 | 7 |
| Thurgau | 38 | 39 | 39 | 39 | 36 | 41 | 37 | 36 | 38 | 46 | 67 | 76 | 84 | 88 |
| Ticino | 100 | 100 | 100 | 98 | 97 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Vaud | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Valais | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Neuchâtel | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 67 | 70 | 68 |
| Genève | 90 | 90 | 89 | 88 | 90 | 89 | 81 | 93 | 91 | 88 | 88 | 91 | 92 | 93 |
| Switzerland | 51 | 54 | 55 | 58 | 59 | 62 | 60 | 64 | 72 | 73 | 75 | 77 | 78 | 79 |

Note: The canton of Jura is not in this table, since it was only created in 1979.
Source: Wespi (1962)

Table 1A-2: Goiter rates and number of observations by canton

| Canton of Birth | 1970 Population-weighted average goiter rate | Number of observations |
|---|---|---|
| Zürich | 8.69 | 401656 |
| Berne | 14.38 | 540017 |
| Luzern | 13.32 | 163472 |
| Uri | 1.97 | 23668 |
| Schwyz | 4.59 | 54857 |
| Obwalden | 4.24 | 17358 |
| Nidwalden | 4.87 | 15925 |
| Glarus | 4.87 | 26672 |
| Zug | 9.71 | 26395 |
| Fribourg | 20.16 | 130704 |
| Solothurn | 7.38 | 120707 |
| Basel-Stadt | 7.45 | 95673 |
| Basel-Landschaft | 5.36 | 73803 |
| Schaffhausen | 3.03 | 38522 |
| Ap. Ausserrhoden | 5.38 | 40949 |
| Ap. Innerrhoden | 3.37 | 13807 |
| St. Gallen | 5.77 | 232667 |
| Graubünden | 3.61 | 99746 |
| Aargau | 13.91 | 221113 |
| Thurgau | 2.43 | 103106 |
| Ticino | 1.15 | 109378 |
| Vaud | 1.96 | 216993 |
| Valais | 5.68 | 120191 |
| Neuchâtel | 5.21 | 80368 |
| Genève | 1.50 | 71884 |
| Jura | 2.96 | 46656 |
| Total Switzerland | 8.49 | 3086287 |

Sources: Bircher (1883) and Federal Statistical Office (1970)

# Chapter 2

# The effects of the generalized use of iodized salt on occupational patterns in Switzerland.

## 2.1 Introduction

Nutrition is inextricably linked to a population's health capital. Malnutrition, especially when it occurs early in life, can have serious detrimental effects on a person's lifetime productivity and economic prospects. Micronutrient deficiencies are a common source of malnutrition, caused by insufficient intake of necessary vitamins and minerals. Iodine is one such micronutrient.

Lack of iodine causes many disorders, the most common of which is an enlargement of the thyroid gland, when there is not enough iodine for the production of hormones which regulate metabolism. This enlargement is called a goiter. Other symptoms include short stature and deaf-mutism. However, the most catastrophic consequence of iodine deficiency is brain damage, which is irreversible and can go unnoticed in a population. Iodine deficiency results in various degrees of mental underdevelopment when it occurs in utero and the first three months of life. Cretinism, which is an acute form of mental retardation, often coupled with goiter and deaf-mutism, occurs when iodine deficiency is utero is most severe.

Iodine deficiency is the leading cause of preventable mental retardation in the world today. The WHO estimates that nearly 50 million people suffer some degree of mental impairment due to a lack of iodine in their diets[1]. According to WHO's Global Database on Iodine Deficiency, more than 285 million children receive inadequate amounts of iodine in their diet [2]. Despite efforts to decrease the prevalence of iodine deficiency in the 1990s, there are still 38 million children born annually at

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

[2] Source: de Benoist et al., eds (2004).

the risk of developing iodine deficiency disorders. The most vulnerable areas in the world are South Asia and Central and Eastern Europe (UNICEF 2008).

Although iodine deficiency is eradicated in developed countries today, the picture looked quite different in early 20th century. Many countries, for reasons related to their geography, had "pockets" of endemic iodine deficiency within their boundaries. For example, the area around the Great Lakes in the USA, as well as some Northwestern states had rates of iodine deficiency that were only paralleled by the prevalence in the Swiss Alps. Indeed, Switzerland was the worst-afflicted country in the world, because its soil has been stripped of its iodine content in many localities during the last Ice Age.

This paper estimates the effects of iodine deficiency eradication on occupational patterns using data from Switzerland. Switzerland was the first country in the world to introduce iodized salt in 1922. It was the first major nutritional intervention ever recorded. Iodized salt proved a cost-effective measure to eradicate endemic goiter, which is an enlargement of the thyroid gland, occurring when there is not enough iodine in the body. The invisible effects of iodine deficiency on mental development and cognitive ability were not fully understood at the time, and public health authorities did not know that they were fighting against mental retardation as well as endemic goiter. As a result of the countrywide iodization campaign, there were no more endemic cretins born after 1930, deaf-mutism rates dropped significantly, and goiter disappeared in children and young recruits (Bürgi et al. 1990). Salt iodization also had a significant impact on graduation rates of those born in highly-deficient areas (Politi 2009). In this paper I find that occupational patterns in previously-deficient areas changed too, reflecting a shift towards higher-paying occupations, and also towards occupations with a lower physical- and a higher cognitive-skills component.

I use microdata from the comprehensive 1970 Swiss Census, combined with data on occupational characteristics. I identify the effect of iodization on occupational patterns by exploiting variation in pre-existing prevalence of iodine deficiency, and also differences in the timing of adoption of iodized salt across localities. I also use a fuzzy regression discontinuity design, where I identify the effect of iodization by looking at sudden jumps in iodized salt sales, and then compare occupational outcomes for cohorts born right before and right after the jump. Overall, I find that iodine deficiency eradication pushed cohorts affected by it towards higher-paying occupations, and occupations with higher cognitive demands. My estimates imply that between 37% and 45% of the shift towards higher-paying occupations that took place in high-goiter areas over that period is accounted for by the eradication of iodine deficiency.

The rest of the paper is organized as follows: Section 2.2 provides some background on iodine deficiency disorders, and section 2.3 describes the campaign for salt iodization in Switzerland. Section 2.4 describes the data used to define the sources of variation for my identification. Section 2.5 describes the Swiss Census microdata, as well as the occupational variables used to identify the effect of iodization on occupations. Sections 2.6 outlines my identification strategy, and empirical results are presented on sections 2.7 and 2.8. Section 2.9 concludes.

## 2.2 Iodine Deficiency Disorders

Iodine, together with Iron and Vitamin A, is a necessary micronutrient, found in very small quantities in the human body. Most of the body's iodine is located in the thyroid gland. Iodine is essential in the synthesis of the two thyroid hormones which regulate metabolism and "play a determining part in early growth and development of most organs, especially of the brain" (Delange 2001).

When the thyroid does not receive sufficient amounts of iodine it adapts by enlarging in order to maximize the use of available iodine. This enlargement is called a goiter, and it is one of the many symptoms of iodine deficiency. Goiters can occur at any point in one's lifetime, whenever the iodine intake is not sufficient. Some goiters are reversible, especially in young individuals. Reversing goiter in adults is harder, especially when they have been subject to iodine deficiency for many years.

Goiter is a visible effect of iodine deficiency. Apart from goiter, however, iodine deficiency can have irreversible and harder to observe consequences if it occurs in utero and in the first three months of life. Iodine deficiency in utero results in various degrees of mental retardation and abnormal brain development, which might even go undetected in a population. In the worst case scenario, severe iodine deficiency causes cretinism. Cretinism is an acute condition characterized by a combination of mental retardation, stunting and physical deformation. Bleichrodt and Born (1994) estimate that the average IQ of iodine-deficient groups is 13.5 points lower than the non-deficient groups[3]. If this is true, then iodine deficiency should have sizable economic effects for any afflicted population. It is this "intelligence-enhancing" aspect of correcting iodine deficiency in a population that is at the heart of this paper.

Endemic goiter and endemic cretinism are primarily due to the geographic location of a population. The main store of iodine is the ocean. As ocean water evaporates, iodine falls on the upper layers of soil through rainfall. Therefore, geographic areas close to the ocean are naturally rich in iodine. On the contrary, regions subject to heavy rain or intense glaciation in the past may be iodine-poor due to soil erosion. It takes thousands of years for rain water to replenish the superficial layers of soil with iodine, so the iodine content of the soil and water of those regions is extremely low. Regions naturally poor in iodine include mountainous areas such as the Andes, the Alps, the Pyrenees, and the Himalayas (Koutras et al. 1980).

A more detailed description of iodine deficiency disorders is provided in Politi (2009).

Iodine has been explicitly used in the treatment of goiter ever since Bernard Courtois isolated it as an element in 1811[4]. The idea that endemic goiter is due to iodine deficiency was first put forward in 1846, by Jean-Louis Prévost and A.C. Maffoni (Prévost and Maffoni 1846). Even though cretinism was associated with endemic goiter, the crucial role of iodine in mental development was not understood until more than a century later. When large-scale interventions of iodine supplementation took place around the 1920s and after, the objective was goiter eradication. People did not know that they were also fighting against mental retardation.

[3] This estimate is based on a meta-analysis of 21 studies of the effect of iodine deficiency on cognitive ability.

[4] However, iodine-rich foods and plants, such as seaweed, were used by ancient civilizations, such as the Chinese and the Greeks, to treat the swelling of the neck before the isolation of iodine as an element.

After doctors started prescribing iodide to their patients in order to fight goiter, toxic side-effects resulting from over-dosing triggered opposition to the universal use of iodine. The first larger-scale iodine supplementation program took place from 1917 to 1922 in Akron, Ohio, and it involved administering sodium iodide regularly to schoolgirls from 5th grade and above. When it began, the intervention was very controversial, but its undeniable success in decreasing the young girls' goiters paved the way for larger-scale programs in the USA and in Europe.

Iodized salt started circulating in Switzerland in 1922. Almost simultaneously, fortification of salt with iodine began in the USA, where iodized salt first appeared in 1924. Both interventions eliminated endemic cretinism and goiter in children, and they decreased goiter prevalence in adults, even though they were followed by an initial spike in goiter-related surgeries and deaths, which then subsided[5]. Information on the program in Switzerland is provided in the following section.

## 2.3 Swiss Iodization Campaign

Switzerland was known for its high prevalence of goiter and cretinism since ancient times (Roman writers mentioned it in their works). During Napoleonic Wars, the low performance of Swiss recruits for the French Army troubled Napoleon and the local authorities in today's canton of Valais. Under Napoleon's orders, a survey was conducted, which showed an extremely high prevalence of cretinism in the population (Bürgi et al. 1990). Further studies revealed that Switzerland had a much higher rate of goiter and cretinism than any of its neighboring countries (Italy, France, Germany).

Swiss data on goiter prevalence confirmed the link between iodine deficiency and goiter prevalence: the canton of Ticino ranked the lowest among cantons in goiter prevalence. This is to be expected, since Ticino is in the southernmost part of Switzerland, bordering Italy and enjoying a milder climate, proximity to the Mediterranean Sea and possibly more iodine-rich foods coming from Italy than the rest of the country. Another canton with unusually low goiter prevalence was Vaud. Historically, Vaud had an exclusive salt mine, which was rich in iodine (Bürgi et al. 1990, p.581).

As a result of the studies showing the extent of the goiter problem, a Swiss Committee for the study of goiter was established in 1907. At that time, goiter was still attributed to some agent in the drinking water, even though experiments with iodine supplementation for the treatment of goiter were already taking place in France and, later, in the USA. Right before his death in 1917, Kocher suggested goiter treatment with small doses of iodine (Bürgi et al. 1990).

The first canton to iodize salt was Appenzell-Ausserrhoden, where iodization started in February 1922, with the initiative of a local doctor, H. Eggenberger. In June 1922, the Swiss Goitre Commission recommended the addition of small amounts of iodine in salt and the additional weekly consumption of iodine tablets by schoolchildren. In November 1922, the Swiss salt monopoly [United

[5]This adverse consequence of iodine supplementation was due to the existence of nodular goiters in the population. Nodular goiters were caused by chronic iodine deficiency. Nodular goiters may become toxic following a sudden increase in iodine intake after a long period of deprivation. This side-effect of iodization is known as iodine-induced hyperthyroidism).

Swiss Rhine Salt Works (USRSW)[6]] started adding iodine to salt and selling the new product at the same price as non-iodized salt. Even before that date, though, iodine prophylaxis had become popular by means of tablets or other supplements. After the recommendations of the Swiss Goiter Committee and the success of salt iodization in Appenzell-Ausserrhoden, the other cantons started allowing the sale of iodized salt in their markets.

Not all cantons introduced iodized salt simultaneously, though. For instance, Valais iodized in 1925, Zürich in 1932 and Bern in 1936[7]. On the other hand, Aargau and Basel-Land didn't iodize until 1952 and 1950 respectively. In 1925 fewer than one fourth of cantons had iodized salt sales that exceeded 60% of total salt sales. By 1945 fewer than one fourth of cantons had salt sales that were below 20% of total salt sales. By 1955, iodized salt sales exceeded 60% of total salt sales in all cantons, and in many of them only iodized salt was sold and consumed (Wespi 1962).

The success of the iodization program was indisputable. According to Bürgi et al. (1990), "no new endemic cretins born after 1930 have been identified" (p.577). Deaf-mutism rates fell sharply for cohorts born after 1922. In Appenzell-Ausserrhoden, which was the first canton to provide iodized salt to its inhabitants, the prevalence of goiter in newborns fell from 20% to 6.4% within the first year after iodization. The prevalence dropped further when, in later years, the iodine content of salt was raised. The beneficial effects on iodization were also seen in the increased height of 6-year-olds entering school, as well as young recruits. In the city of Lausanne, 23.7% of young recruits had large goiters in 1924/1925, but the figure had dropped to 0.2% by 1983-1987 (Bürgi et al. 1990).

More information on the Swiss Iodization Campaign is provided in Politi (2009).

## 2.4 Bircher's monograph and Iodized Salt Sales

To identify the effect of iodization on occupational outcomes, I employ two sources of variation: the first in the naturally-occurring geographical variation in underlying iodine deficiency prior to the generalized use of iodized salt. The second source of variation arises because of differences in the timing of adoption of iodized salt across Swiss localities.

In 1883, Swiss physician Heinrich Bircher published a monograph with details on the geographic variation in goiter rates across Switzerland (Bircher 1883). Over the period 1875-1880, he toured every town and village in Switzerland and recorded goiter cases in recruits, which served as a proxy for goiter prevalence in the local population. Bircher's monograph was eye-opening to public health authorities at the time, because it showed the extent of the problem across the country, and also the big differences in goiter prevalence, even in villages within a short distance from each other. The data correlates well with measurements of iodine content of the water and soil across Swiss localities.

I use the data collected by Bircher to group Swiss districts according to their goiter prevalence. Goiter prevalence serves as a proxy for underlying iodine deficiency in the population. I classify a

[6] USRSW was "the exclusive supplier of salt to 24 of the 25 cantons" of Switzerland, the exception being the canton of Vaud (Bürgi et al. 1990, p.582).

[7] This is the first year that the cantons' iodized sales exceeded 40% of total salt sales.

district as being "high-goiter" if it belongs to the top 25% of the population-weighted goiter distribution. This corresponds to districts where goiter prevalence was 11.7% or higher. Correspondingly, a district is "low-goiter" if its goiter prevalence is within the lowest 25% of the goiter distribution in the population, corresponding to goiter rates lower than 3.5%. High-goiter districts are where I expect to observe the treatment effect of iodization. On the contrary, I expect the treatment effect to be much lower in low-goiter districts.

After iodized salt became available in 1922, it was not adopted at the same time or speed by all cantons. Some cantons, such as Nidwalden and Schaffhausen, were early adopters, whereas other cantons, such as Aargau, Basel-Stadt, and Basel-Land were much slower. The sale of iodized salt had to be approved and allowed by each canton's constitution. In 1962 H. J. West, M.D. and Chief Doctor of Women's Clinic in Aarau, published a paper containing data on yearly iodized salt sales as a percentage of total salt sales per canton, from 1922 to 1961 (Wespi 1962). These data show how widespread the use of the "new salt" was at any point in time.

Some cantons, such as Schwyz and Luzern made a very fast transition to iodized salt, whereas for other cantons, such as Thurgau and Graubünden, the transition was much more gradual. It appears that low-goiter cantons were the ones that adopted iodized salt earlier than highly-affected cantons. This reluctance from the part of those most likely to benefit from the intervention is puzzling at first. However, one needs to take into account that this was the first major nutritional intervention to ever take place, and it was not without controversy, especially in light of many thyroid-related deaths resulting from iodine overdoses to people who had been severely deficient throughout their lives. It is reasonable to expect those cantons where the stakes were higher to be the ones where the transition took the longer to finally occur, since public debate on the issue would have been more heated.

I use the data contained in West's paper as a measure of treatment. Also, based on West's data I construct a variable corresponding to one's age relative to iodization in their canton of birth. In particular, I identify jumps in the sales of iodized salt, and I look at individuals' occupational choice outcomes, comparing those born right before and right after the jump in sales. This is feasible because once one takes a glance at the data, it becomes obvious that most cantons had a steep transition to iodized salt, as opposed to a more gradual adoption.

For more information on Bircher's monograph and on the geographic variation of goiter prevalence, as well as on the iodized salt sales data, and how iodized salt adoption coincides with a drop in deaf-mutism rates, see Politi (2009).

## 2.5 The 1970 Swiss Census and Dictionary of Occupational Titles

I identify the effect of iodization on occupational choice using microdata from the 1970 Swiss Census (Federal Statistical Office 1970), which includes detailed information on a person's year and location of birth. Switzerland is a federation made up of 26 cantons (comparable to US States, but much

Table 2.1: Actively employed individuals in 1970 Swiss Census

| | **Active** | **Non-active** | **Total** |
|---|---|---|---|
| Males | 1,149,692 | 109,524 | 1,259,216 |
| Females | 475,708 | 841,009 | 1,316,717 |
| Total | 1,625,400 | 950,533 | 2,575,933 |

(Source: 1970 Swiss Census)

smaller), 184 districts and 2896 municipalities. The 1970 Swiss Census records an individual's municipality of birth. This low level of aggregation is particularly important, because endemic iodine deficiency was a very localized phenomenon, and it depended on the iodine content of a population's local sources of food and water. Municipalities within a short distance of each other might have had very different exposure to iodine before iodized salt was introduced, so it is important to know in as much detail as possible the location of one's birth.

I use all individuals born in Switzerland from 1900 to 1944 (inclusive) whose occupation is recorded in the Swiss Census. Unfortunately, this only includes people actively employed (both part- and full-time) at the time of the Census. This excludes most women in my sample. Table 2.1 shows that out of 2,575,933 individuals born in the period 1900-1944, only 1,625,400 held a job in 1970, and only 36% of females were active in the labor force.

The 1970 Swiss Census contains detailed information on each individual's occupation, using 4-digit codes according to the International Standard Classification of Occupations (ISCO). Using these data, and grouping individuals into 9 broad occupation categories (according to the first digit of their ISCO code), I construct an indicator variable for whether an individual was employed in the top three occupational categories. These categories include individuals employed in executive/managerial positions, senior officials and legislators, professionals such as physicians, engineers and lawyers, as well as technicians and associate professionals such as police inspectors, trade brokers, and health associates. These occupational categories have earned higher wages historically, compared to the other categories of occupations in the data. For example, in the second trimester of 2007, the annualized median income of full-time workers in these top categories was over 84,000 Swiss Franks or more, whereas the corresponding number for all other occupation categories was less than 65,000 Swiss Franks (Communication from the Swiss Federal Statistical Office). Occupational groups not included in the three top categories include clerks, service and shop sales workers, skilled agricultural workers, craft and related trades workers, machine operators, and people employed in elementary occupations such as street vendors, cleaners, and unskilled laborers. Table 2.2 shows how many individuals were employed in each of the nine broadly-defined occupational categories in the 1970 Swiss Census. A little over 25% of individuals (almost 29% of males) are employed in the three higher-paying occupational categories.

I combine the occupational data of the 1970 Swiss Census with data on occupational characteristics compiled by Paula England and Barbara Kilbourne from the Dictionary of Occupational

Table 2.2: Broad occupational categories in 1970 Swiss Census

| | **Occupational Category** | **Males** | **Females** | **Total** |
|---|---|---|---|---|
| High-paying occupations | 1: Legislators, senior officials, managers | 85,317 | 20,317 | 105,634 |
| | 2: Professionals | 78,644 | 18,934 | 97,578 |
| | 3: Technicians and Associate Professionals | 168,871 | 55,286 | 224,157 |
| | 4: Clerks | 157,625 | 117,620 | 275,245 |
| | 5: Service, shop and market sales workers | 47,697 | 104,859 | 152,556 |
| | 6: Skilled agricultural and fishery workers | 124,209 | 41,832 | 166,041 |
| | 7: Craft and related trades workers | 311,402 | 53,799 | 365,201 |
| | 8: Plant and machine operators and assemblers | 122,068 | 19,133 | 141,201 |
| | 9: Elementary Occupations | 53,859 | 43,928 | 97,787 |
| | Total | 1,149,692 | 475,708 | 1,625,400 |

(Source: 1970 Swiss Census)

Titles for 1980 US Census Detailed Occupations (England and Kilbourne 1988). The dataset is available in electronic format and freely distributed by the Inter-university Consortium for Political and Social Research (ICPSR). These data contain scores on a variety of characteristics for all occupational codes used in the 1980 US Census. For example, occupations get scores according to verbal, numerical, spatial, and other aptitudes needed to perform the job, as well as the physical demands of the job.

I match occupational codes from the 1980 US Census with ISCO codes, which are used in the coding of occupations in the Swiss Census. In this way, I am able to get scores of many occupational characteristics and merge them with the 1970 Swiss Census. As for many four-digit ISCO categories there were no entries or a direct correspondence with US Occupational codes, I aggregate ISCO codes to three-digit categories, and compute the average value of each characteristic in each category.

I look into eight occupational characteristics, grouped into two categories: physical requirements and cognitive demands of occupations [This is the same methodology as the one used in Case and Paxson (2006).]. The variables corresponding to physical requirements are manual dexterity, motor coordination, physical demands (such as climbing, kneeling, and reaching), and strength. The variables related to the cognitive requirements of a given occupation are spatial, verbal, and numerical aptitude, as well as intelligence. As in Case and Paxson (2006), in some cases I reverse-coded some of these variables, in a way that a higher value corresponds to higher requirements for a given characteristic in an occupation. Values for each characteristics typically range from 1 to 5, except in the case of physical demands, which ranges from 0 to 4, and motor coordination and intelligence, which range from 1 to 4.

As expected, cognitive requirements such as verbal and numerical aptitude tend to have higher values for occupations in upper ISCO categories (1, 2, 3), whereas the opposite is true for physical requirements such as manual dexterity and strength. This is shown in table 2.3, which lists average scores and standard deviations for each job characteristic for each broad ISCO category. For example, legal professionals (a sub-category of ISCO category 2, which includes lawyers and judges) have really high scores for numerical and verbal aptitude (4.2 and 4.4 respectively). On the contrary, this occupational category only has a score of 0.4 for physical demands, and 1.2 for strength. On the other hand, agricultural laborers (part of ISCO category 9) have scores of 2 and 2.2 for numerical and verbal aptitude, whereas they have scores of 2.9 and 3.5 for physical demands and strength.

## 2.6 Identification using geographical and temporal variation

The main idea behind the identification strategy is to use two sources of variation in order to identify the effect of iodization on occupational outcomes. The first source of variation is geographical; not all areas in Switzerland were affected by iodine deficiency to the same extent. What defined the prevalence of iodine deficiency across localities was the iodine content of soil and drinking water, which in turn was determined by geological developments in that areas, which took place thousands of years before the period of study. Using Bircher's rich dataset, I am able to identify districts where the prevalence of goiter was very high, signifying a high prevalence of underlying iodine deficiency in the population. I treat all districts where goiter rates are at the top 25% of the population-weighted goiter distribution as being high-goiter. These are the districts where goiter prevalence is 11% or higher.

I expect iodization to have a greater impact on the cognitive ability of those populations born in high-goiter districts compared to any effects measured for people born in low-goiter districts. Thus, this source of variation identifies a treatment group (people born in high-goiter districts) and a control group (people born in low-goiter districts).

The second source of variation is temporal; once the salt monopoly started producing iodized salt, each canton had to authorize its sale by amending its constitution. As a result, the "new product" did not become available across all cantons at the same time. Therefore, people born after iodized salt was introduced constitute the treated population, whereas people born before iodization are a control group.

As discussed in section 2.4, a glance at the data shows that high-goiter cantons allowed the sale of iodized salt later, compared to low-goiter cantons. This might reflect reluctance from the part of the authorities in those cantons to introduce such a far-reaching public health measure, in light of the debate ignited by the spike in thyroid-related deaths following iodine overdose in some chronically deficient populations. If this is the only reason of the different timing between high- and low-goiter cantons, then that should not pose a problem for my identification.

The non-random nature of the difference in the timing of adoption is problematic for my identification strategy to the extent that it reflects time-variant unobserved differences between high- and low-goiter cantons, which affected the timing of adoption of iodized salt in the 1920s and 1930s, and also affected occupational patterns many years later, when the treated population entered the labor market. Although it seems unlikely that a common unobserved factor would affect both these

Table 2.3: Job characteristics for occupational categories in 1970 Swiss Census

| ISCO category | Manual Dexterity | Motor Coordination | Physical Demands | Strength |
|---|---|---|---|---|
| 1 | 2.2052 | 2.1933 | 0.7502 | 1.7039 |
| | (0.0680) | (0.0557) | (0.2306) | (0.1341) |
| 2 | 2.5256 | 2.4086 | 1.0425 | 1.7536 |
| | (0.5371) | (0.3076) | (0.6282) | (0.3077) |
| 3 | 2.5544 | 2.5896 | 1.3572 | 1.8623 |
| | (0.4548) | (0.3985) | (0.7021) | (0.3315) |
| 4 | 2.6782 | 3.0950 | 1.7675 | 1.5043 |
| | (0.0961) | (0.4348) | (0.2062) | (0.4200) |
| 5 | 2.5622 | 2.5112 | 1.4389 | 2.2582 |
| | (0.1734) | (0.2752) | (0.3600) | (0.2722) |
| 6 | 2.5081 | 2.2774 | 3.0692 | 3.4742 |
| | (0.0653) | (0.0633) | (0.1572) | (0.0812) |
| 7 | 3.2093 | 2.8661 | 2.6782 | 2.8385 |
| | (0.2143) | (0.0818) | (0.5528) | (0.3927) |
| 8 | 2.8371 | 2.7467 | 2.0387 | 2.6882 |
| | (0.0898) | (0.1407) | (0.1684) | (0.2429) |
| 9 | 2.9034 | 2.4706 | 2.3261 | 3.1635 |
| | (0.0554) | (0.1305) | (0.2928) | (0.2992) |
| Total | 2.7578 | 2.6830 | 2.0061 | 2.3790 |
| | (0.3795) | (0.8017) | (0.7382) | (0.7382) |

| ISCO category | Spatial Aptitude | Numerical Aptitude | Verbal Aptitude | Intelligence |
|---|---|---|---|---|
| 1 | 2.3255 | 3.1489 | 3.7353 | 2.8395 |
| | (0.1013) | (0.0665) | (0.0779) | (0.0881) |
| 2 | 3.1514 | 3.7347 | 4.3509 | 3.4330 |
| | (0.6944) | (0.4738) | (0.2069) | (0.2345) |
| 3 | 2.6859 | 3.1512 | 3.5000 | 2.6139 |
| | (0.5859) | (0.3687) | (0.3124) | (0.2569) |
| 4 | 2.2449 | 2.6962 | 3.1454 | 2.1783 |
| | (0.129) | (0.1324) | (0.0909) | (0.0719) |
| 5 | 2.3215 | 2.6254 | 2.8821 | 1.9442 |
| | (0.2453) | (0.3455) | (0.2330) | (0.2058) |
| 6 | 3.0425 | 2.6244 | 2.7457 | 2.2911 |
| | (0.1222) | (0.1009) | (0.0624) | (0.1289) |
| 7 | 3.1094 | 2.6329 | 2.7408 | 1.9864 |
| | (0.3124) | (0.1953) | (0.1531) | (0.0980) |
| 8 | 2.6209 | 2.3042 | 2.5312 | 1.7804 |
| | (0.1900) | (0.2146) | (0.2015) | (0.2091) |
| 9 | 2.4313 | 2.1324 | 2.3319 | 1.5312 |
| | (0.0934) | (0.1665) | (0.1096) | (0.1009) |
| Total | 2.7014 | 2.7381 | 3.0214 | 2.2071 |
| | (0.4879) | (0.4460) | (0.5258) | (0.4714) |

(Source: 1970 Swiss Census and England and Kilbourne (1988)) outcomes, I do introduce a linear, canton-specific time trend in all specifications.

Combining the geographical and temporal sources of variation, the treatment group includes **people born in high-goiter districts after iodized salt was introduced**. On the contrary, people born in low-goiter districts, and people born before iodization form the control group.

### 2.6.1 Iodized salt sales and birth location

I introduce iodized salt sales at the canton level directly as a regressor. The outcome variables include an indicator for being employed in a high-paying occupation (as defined by belonging to the top 3 ISCO one-digit occupational categories), as well as each of the 8 occupational characteristics described in section 2.5.

In particular, I control for the percentage of iodized salt sales in total salt sales one year prior to birth in one's canton of birth. I also control for canton and cohort fixed effects, to remove the effect of any omitted variables that are canton- or cohort-specific. In addition, I introduce a canton-specific time trend, to control for any other gradual changes that might have affected one's occupational outcomes.

I run the following regression for an individual $i$ born in canton $c$ in year $y$:

$outcome_{idy} = \alpha + \beta\cdot$ *Iodized salt 1 year prior to birth*

$+$ *Canton of birth Fixed Effects*

$+$ *Canton of birth time trend*

$+$ *Cohort of Birth Fixed Effects* $+\epsilon_{idy}$,

where standard errors are clustered at the canton-cohort level.

I estimate the above regression for the sample as a whole and then separately by gender. I cluster standard errors on the canton of birth - cohort level. My sample includes all individuals born in Switzerland between 1900 and 1944 (inclusive), for whom occupational data were recorded during the 1970 Census.

### 2.6.2 Jumps in iodized salt sales; a Fuzzy Regression Discontinuity Approach

I use West's data on the percentage of iodized salt sales to get information on the timing and speed of iodization in each canton. Most cantons experienced a big jump in iodized salt sales within a period of 1 to 2 years, so that the timing of the intervention is easy to identify in the majority of cases. The probability of someone being treated with adequate iodine in utero changes discontinuously depending on whether they were born before or after the jump in sales. I use these jumps in a "fuzzy regression discontinuity" (FRD) framework (for a description of FRD see, for example, Imbens and Lemieux (2008)).

Based on the year of the jump in iodized salt sales, which is particular to each canton, I construct a new variable, age relative to iodization, which will be common across all people born in the same canton in the same year, but will generally be different across cohorts born in different cantons.

Because of the difference in the timing of adoption, I can control for unobserved, time-invariant canton characteristics, as well as unobserved, space-invariant cohort characteristics, and a cantons-specific trend. Since these jumps all occurred in a small window of time, this method is "cleaner" than a simple regression of outcomes on iodized salt sales, as there are fewer possible confounding effects taking place within same small time frame in a particular canton.

I check for some preliminary evidence of how being born in a high-goiter district right after a jump in iodized salt sales affects one's occupational outcomes, after controlling for district and cohort of birth fixed effects, as well as a district-specific time trend.

I run the following regression for an individual $i$ born in district $d$ in year $y$:

$outcome_{idy} = \alpha + \beta\cdot$ *1 (Born in high-goiter district) X 1 (Born after jump in sales of iodized salt)*
+ *District of birth Fixed Effects*
+ *District of birth time trend*
+ *Cohort of Birth Fixed Effects* $+\epsilon_{idy}$,

where outcomes are an indicator variable for being employed in a high-paying occupation, as well as the occupational characteristics described in section 2.5. Standard errors are clustered at the district-cohort level. First, I run the regression on the whole sample, and then for males and females separately. I first use the whole sample and then only the sub-sample of those people born within ten years of the jump in iodized salt sales. In some specifications I use cohort fixed effects that are common for high-goiter districts and the rest of the country, whereas in others I allow cohort fixed effects to be different for high-goiter districts.

Next, I follow the FRD approach, and regress outcomes on the percentage of iodized salt sales (at the canton-level) one year prior to birth (and additional controls), but I instrument iodized salt sales with an indicator variable equal to 1 if someone is born after the big jump in sales which marked each canton's decisive transition to iodized salt.

I run the following regression for an individual $i$ born in canton $c$ in year $y$:

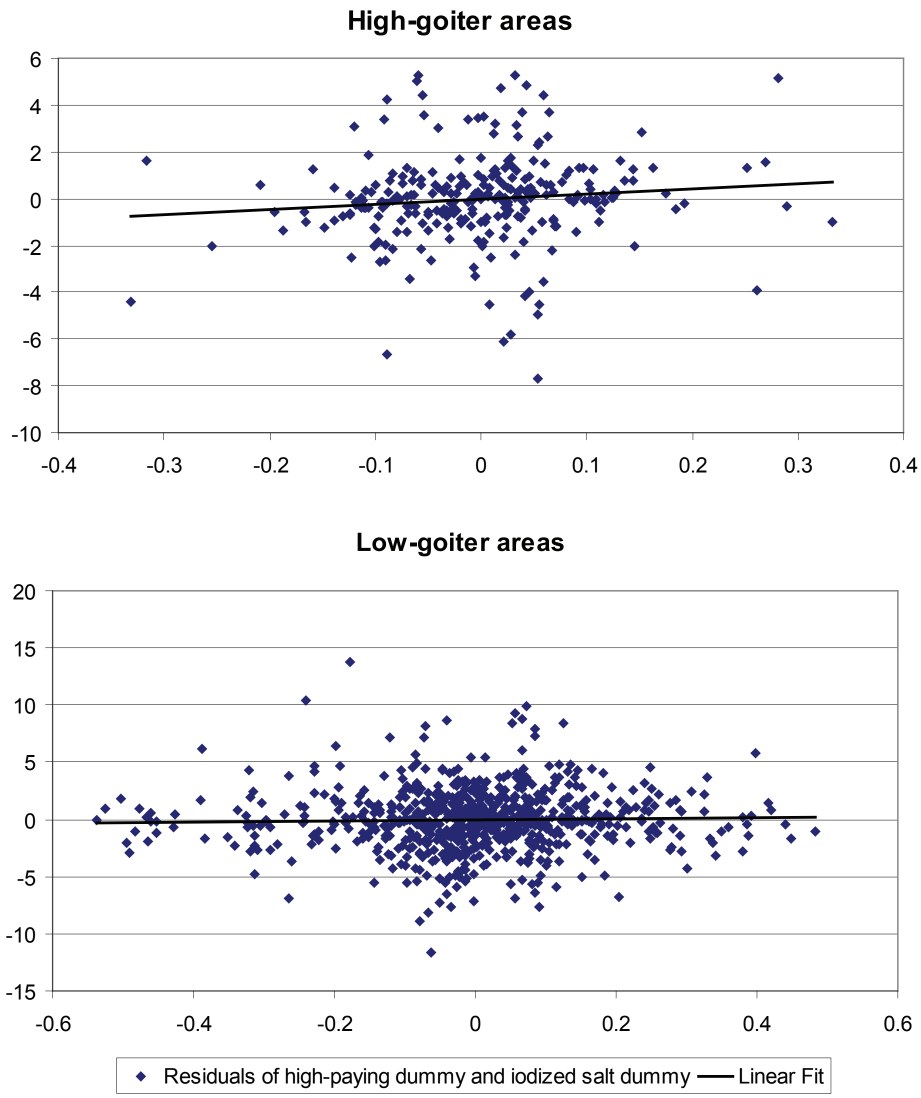
$outcome_{idy} = \alpha + \beta\cdot$ *Iodized salt 1 year prior to birth*
+ *Trend before jump in iodized salt sales*
+ *Trend after jump in iodized salt sales*
+ *Canton of birth Fixed Effects*
+ *Canton of birth time trend*
+ *Cohort of Birth Fixed Effects* $+\epsilon_{idy}$,

where $outcome_{idy}$ is either an indicator variable for being employed in a high-paying occupation, or one of the occupational characteristics described in section 2.5. Standard errors are clustered at the canton-cohort level. I include both a linear canton-specific time trend, but also linear nationwide trends which are allowed to differ before and after the jump in iodized salt sales.

I estimate the treatment effect for the whole sample and all areas, and then I use only those observations corresponding to high- and low-goiter districts, and estimate the effects of iodization separately for each of these two populations. I then estimate effects for males and females separately, using the same cuts of the data.

## 2.7 The effect of Iodization on Occupational Choice

Figure 2.1: Residuals graph of high-paying dummy and iodized salt




**Note:** Scatterplot of average residuals (at the canton-cohort level) from regressing high-paying occupation dummy and iodized salt sales one year prior to birth on year and canton of birth fixed effects, as well as a canton-specific time trend.
(Source: 1970 Swiss Census and England and Kilbourne (1988))

Figure 2.1 is a graphical representation of the regression results outlined later in this section. Figure 2.1 includes two scatterplots of average residuals (at the canton - year of birth level) from regressing a high-paying occupation dummy and iodized salt sales one year prior to birth on canton and cohort fixed effects, as well as a canton-specific linear trend. The first scatterplot comes from including only those individuals born in high-goiter districts, whereas the second one only includes people born in low-goiter districts. There are fewer observations in the first scatterplot because iodine deficiency was localized in certain parts of the country, so high-goiter districts are found in fewer cantons than low-goiter districts. As a result, when residuals are averaged at the canton - year of birth level, there are fewer observations.

What Figure 2.1 shows is that whereas (regression-adjusted) higher sales of iodized salt around one's time of birth are associated with a (regression-adjusted) higher probability of being employed in a high-paying occupation in the future, such a relationship does not exist for people born in low-goiter areas, where I expect the treatment effect to have been lower.

Table 2.4 shows results from regressing a high-paying occupation dummy on iodized salt sales (1 year prior to birth), as well as canton and cohort fixed effects. I also include a canton-specific linear trend. As shown in table 2.4, this makes the coefficients of interest somewhat bigger. The treatment effect is estimated for the whole sample and then separately by gender, and also for all areas, and then separately for high- and low-goiter districts only. The coefficients in table 2.4 correspond to percentage point changes, and standard errors are clustered at the year and canton of birth level.

Looking at the sample as a whole, the treatment effect is significant (when I include the canton-specific trend) but very small for the country as a whole. However, when I limit the sample to those observations to individuals born in high-goiter areas, the effect of iodization increases both in magnitude and significance. Specifically, born in a high-goiter district after iodized salt sales have gone from 0% to 100% increases one's probability of employment in the top occupational categories later in life by 3.2 percentage points. Given that less than a third of the population as a whole is employed in these categories over the period of examination, this is a significant increase in one's chances of receiving higher wages. Low-goiter districts, as expected, were not affected.

When I break the sample down by gender, it is clear that most of the effect of iodization is driven by males. This is a departure from the conclusion reached in Politi (2009), where the effect of iodization on increased schooling was mainly driven by the effect on females. However, in this case females did not participate in the labor force as regularly as males, so there are much fewer female observations. Indeed, only a third of females in my sample were recorded as being employed. In addition, female selection into employment was probably not random, therefore it is hard to make any meaningful conclusions about the effect of iodization on occupational characteristics for females.

Results which are similar in direction but smaller in magnitude are shown on table 2.5, which estimates a departure from trend in outcomes for those born in high-goiter districts following a jump in iodized salt sales. Table 2.5, in particular, shows results from a regression of a high-paying occupation indicator variable on an indicator variable for being in the treatment group (which is the interaction of two indicator variables: being born in a high-goiter district, and being born after a jump in iodized salt sales). The regression also includes district fixed effects, a district-specific time trend (I also show results without including the district-specific trend, and they are very similar), and year of birth fixed effects, which in columns (1) and (3) are the same for high-goiter districts

Table 2.4: Salt sales and occupational choice

Salt sales and occupational choice: Coefficient on Iodized Salt 1 year prior to birth

| | WHOLE SAMPLE | | |
|---|---|---|---|
| | ALL AREAS | HIGH-GOITER | LOW-GOITER |
| High-paying occupation dummy | 0.69367** | 3.20205*** | -0.14225 |
| | (0.30658) | (0.67162) | (0.40538) |
| Canton-specific trend | YES | YES | YES |
| Number of Observations | 1620246 | 402781 | 397334 |
| R-squared | 0.0176 | 0.013 | 0.019 |
| High-paying occupation dummy | -0.02581 | 2.74317*** | 0.39774 |
| | (0.22437) | (0.54258) | (0.35071) |
| Canton-specific trend | NO | NO | NO |
| Number of Observations | 1620246 | 402781 | 397334 |
| R-squared | 0.0174 | 0.013 | 0.0187 |
| | MALES ONLY | | |
| | ALL AREAS | HIGH-GOITER | LOW-GOITER |
| High-paying occupation dummy | 1.00143*** | 3.24884*** | 0.0302 |
| | (0.37611) | (0.93727) | (0.50349) |
| Canton-specific trend | YES | YES | YES |
| Number of Observations | 1145756 | 288765 | 280378 |
| R-squared | 0.0271 | 0.0191 | 0.0288 |
| High-paying occupation dummy | 0.26264 | 3.31585*** | 0.71948* |
| | (0.27115) | (0.7564) | (0.43602) |
| Canton-specific trend | NO | NO | NO |
| Number of Observations | 1145756 | 288765 | 280378 |
| R-squared | 0.0269 | 0.019 | 0.0285 |
| | FEMALES ONLY | | |
| | ALL AREAS | HIGH-GOITER | LOW-GOITER |
| High-paying occupation dummy | 0.07639 | 2.68974** | -0.43441 |
| | (0.38722) | (1.19814) | (0.57743) |
| Canton-specific trend | YES | YES | YES |
| Number of Observations | 474490 | 114016 | 116956 |
| R-squared | 0.0063 | 0.0045 | 0.0089 |
| High-paying occupation dummy | -0.52803* | 1.32781 | -0.16256 |
| | (0.31723) | (0.94442) | (0.51836) |
| Canton-specific trend | NO | NO | NO |
| Number of Observations | 474490 | 114016 | 116956 |
| R-squared | 0.0059 | 0.0044 | 0.0083 |

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%

Coefficients correspond to changes in percentage points.

High-goiter districts are those belonging to the top 25% of the population-weighted goiter distribution.

Low-goiter districts are those belonging to the bottom 25% of the population-weighted goiter distribution.

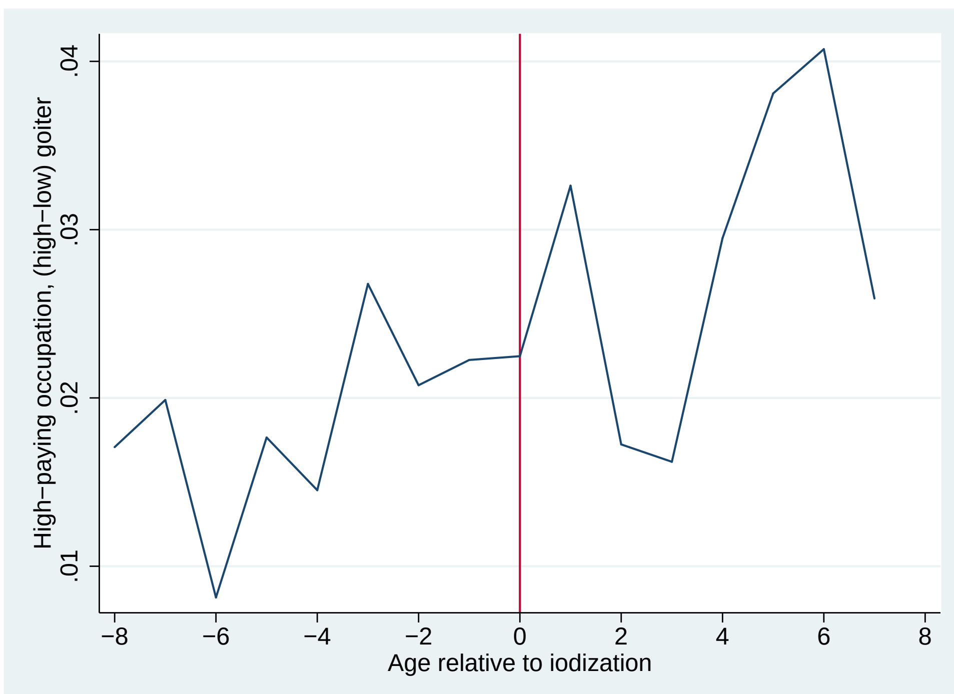
All regressions include people born in Switzerland in 1900-1944 and interviewed for the 1970 Census.

Standard errors in parentheses, clustered at the canton-year of birth level.

and the rest of the country, but which are allowed to be different for high-goiter districts in columns (2) and (4). Standard errors are clustered at the district-year of birth level. Columns (1) and (2) include the whole sample, whereas columns (3) and (4) only include people born within 10 years of the jump in iodized salt sales.

As shown on table 2.5, the treatment effect is concentrated on males, regardless of whether we look at the whole sample or the limited age range. The gain in percentage points for males here is of the order of 1.2 to 1.5 percentage points, which is somewhat smaller than the effect estimated in table 2.4. This might because even before the jump in sales, iodized salt was available and consumed in smaller quantities, so it is likely that part of the control group in this exercise was actually treated with iodine. According to table 2.5 females did not benefit from iodine supplementation. However, as discussed above, this is not necessarily accurate since female labor participation was limited over that period.

Figure 2.2: Regression-adjusted probability of being employed in a highly-paid occupation by age relative to iodization; difference between high- and low-goiter districts




(Source: 1970 Swiss Census and England and Kilbourne (1988))

Figure 2.2 is a plot of the regression-adjusted difference in probabilities of being employed in a high-paying occupation people born in high- and low-goiter districts against age relative to iodization. The line represents the difference in coefficients on relative age indicator variables between those born in high- and low-goiter areas, after factoring out canton and cohort fixed effects, as well as a canton-specific trend. It is the regression equivalent of the “Fuzzy Regression Discontinuity”

Table 2.5: Salt sales and occupational choice if born after jump

Coefficient on high-goiter dummy X Born after jump in iodized salt sales

| | WHOLE SAMPLE | | | |
|---|---|---|---|---|
| | All cohorts | | Born +/- 10 years from jump | |
| | (1) | (2) | (3) | (4) |
| High-paying occupation dummy | 1.10215*** | 1.09991*** | 1.04325** | 0.80215 |
| | (0.33805) | (0.40945) | (0.45021) | (0.53454) |
| District-specific trend | YES | YES | YES | YES |
| Number of Observations | 1625400 | 1625400 | 689302 | 689302 |
| R-squared | 0.029 | 0.029 | 0.0272 | 0.0272 |
| High-paying occupation dummy | 1.20967*** | 0.88392** | 1.1873*** | 0.62239 |
| | (0.3003) | (0.36071) | (0.3248) | (0.46633) |
| District-specific trend | NO | NO | NO | NO |
| Number of Observations | 1625400 | 1625400 | 689302 | 689302 |
| R-squared | 0.0286 | 0.0287 | 0.0268 | 0.0269 |
| | MALES ONLY | | | |
| | All cohorts | | Born +/- 10 years from jump | |
| | (1) | (2) | (3) | (4) |
| High-paying occupation dummy | 1.4672*** | 1.21396** | 1.31045** | 1.1849* |
| | (0.42132) | (0.50823) | (0.54966) | (0.68766) |
| District-specific trend | YES | YES | YES | YES |
| Number of Observations | 1149692 | 1149692 | 489047 | 489047 |
| R-squared | 0.0443 | 0.0443 | 0.0418 | 0.0418 |
| High-paying occupation dummy | 1.55246*** | 1.11773** | 1.68413*** | 0.95469* |
| | (0.39325) | (0.458) | (0.41176) | (0.57837) |
| District-specific trend | NO | NO | NO | NO |
| Number of Observations | 1149692 | 1149692 | 489047 | 489047 |
| R-squared | 0.0439 | 0.044 | 0.0413 | 0.0413 |
| | FEMALES ONLY | | | |
| | All cohorts | | Born +/- 10 years from jump | |
| | (1) | (2) | (3) | (4) |
| High-paying occupation dummy | 0.36269 | 0.84244 | 0.17463 | 0.27335 |
| | (0.56023) | (0.67139) | (0.82643) | (0.83241) |
| District-specific trend | YES | YES | YES | YES |
| Number of Observations | 475708 | 475708 | 200255 | 200255 |
| R-squared | 0.0104 | 0.0105 | 0.0115 | 0.0116 |
| High-paying occupation dummy | 0.48832 | 0.47301 | 0.18643 | 0.20132 |
| | (0.42429) | (0.52234) | (0.5024) | (0.72193) |
| District-specific trend | NO | NO | NO | NO |
| Number of Observations | 475708 | 475708 | 200255 | 200255 |
| R-squared | 0.0095 | 0.0096 | 0.0106 | 0.0107 |

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%

Coefficients correspond to changes in percentage points.

Columns (1) and (3) assume common cohort fixed effects for high- and non-high-goiter districts.

Columns (2) and (4) assume different cohort fixed effects for high- and non-high-goiter districts.

Standard errors in parentheses, clustered at the district-year of birth level.

approach, the results of which are shown on table 2.6 (A short description of the FRD method can be found in section 2.6.2). Figure 2.2 shows that right around the time of a jump in iodized salt sales there was a corresponding jump in a cohort's probability of being employed in a high-paying occupation when they entered the labor market.

Table 2.6 tells the same story. The results of the "Fuzzy Regression Discontinuity" approach are much more similar to table 2.4 than table 2.5 was, although they are still somewhat smaller in magnitude. According to table 2.6, when looking at the country as a whole, iodization seems to not have had much of an effect on people's occupational choice. But the intra-region difference becomes clear when one looks separately at people born in high- and low-goiter districts. People born in high-goiter districts after a jump in iodized salt sales had a higher and significant probability of being employed in a high-paying occupation. The increase in the probability is of the order of 2.3 percentage points, which is economically significant, given the low baseline probability of being employed in the top occupational categories (less than 30%). As in table 2.5, the effect is driven by males, where the probability of being employed in a high-paying occupation rose by 3.1 percentage points.

In high-goiter areas, 23.4% of all people born prior to a jump in iodized salt sales selected into a high-paying occupation, whereas almost 30% of people born after a jump in sales were employed in one of the top three occupational categories. Using my estimates, this means that at least 37% of the change can be directly attributed to iodization. For males, the percentage of people employed in a high-paying occupation rises from 25.4% to 32.2%. If iodization increases one's chances of belonging to that category by 3.1%, then my estimates imply that iodization accounts for almost 45% of the rise in the percentage of males employed in high-paying occupations over that period. Therefore, iodization accounts for a big part of the shift towards higher-paying occupations observed in high-goiter areas over the period of examination.

## 2.8 The effect of Iodization on Characteristics of Occupations

In this section I analyze the effects of the introduction of iodized salt on occupational characteristics. As outlined in section 2.5, I match eight characteristics of occupations from the book *"Occupational Measures from the Dictionary of Occupational Titles for 1980 Census Detailed Occupations"* with ISCO occupational codes used in the Swiss Census (England and Kilbourne 1988). These characteristics sum up the physical and cognitive skills required by a given occupation. The variables used are: *Manual Dexterity, Motor Coordination, Physical Demands, Strength, Spatial Aptitude, Numerical Aptitude, Verbal Aptitude, and Intelligence.* The first four of these characteristics refer to physical skills, whereas the final four reflect cognitive skills required by a given occupation.

Figure 2.3 shows how the mix of four of these characteristics changed differentially for high- and low-goiter areas after iodization. More specifically, figure 2.3 shows the coefficients on an indicator variable equal to 1 if an individual was born after a jump in sales of iodized salt, in a regression which

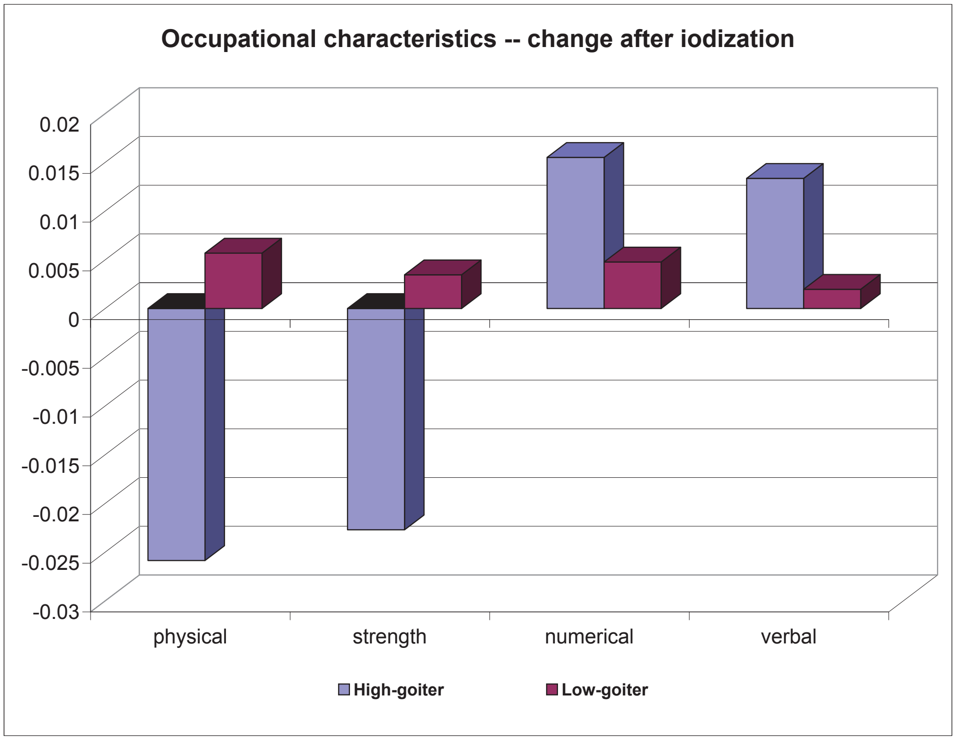
Table 2.6: High-paying occupation: Fuzzy Regression Discontinuity

Salt sales and occupational choice: Coefficient on Iodized Salt 1 year prior to birth

| | WHOLE SAMPLE | | |
|---|---|---|---|
| | ALL AREAS | HIGH-GOITER | LOW-GOITER |
| High-paying occupation dummy | 0.15069 | 2.29497** | -0.42023 |
| | (0.36849) | (0.90451) | (0.40623) |
| Canton-specific trend | YES | YES | YES |
| Number of Observations | 1620246 | 402781 | 397334 |
| R-squared | 0.0176 | 0.0131 | 0.019 |
| High-paying occupation dummy | 0.21984 | 1.71321* | -0.93815** |
| | (0.41011) | (0.9106) | (0.4299) |
| Canton-specific trend | NO | NO | NO |
| Number of Observations | 1620246 | 402781 | 397334 |
| R-squared | 0.0174 | 0.013 | 0.0188 |
| | MALES ONLY | | |
| | ALL AREAS | HIGH-GOITER | LOW-GOITER |
| High-paying occupation dummy | 0.28545 | 3.14385** | -0.28615 |
| | (0.45591) | (1.30235) | (0.5056) |
| Canton-specific trend | YES | YES | YES |
| Number of Observations | 1145756 | 288765 | 280378 |
| R-squared | 0.0271 | 0.0191 | 0.0288 |
| High-paying occupation dummy | 0.47256 | 2.88057** | -0.97047* |
| | (0.49684) | (1.2956) | (0.52103) |
| Canton-specific trend | NO | NO | NO |
| Number of Observations | 1145756 | 288765 | 280378 |
| R-squared | 0.0269 | 0.019 | 0.0286 |
| | FEMALES ONLY | | |
| | ALL AREAS | HIGH-GOITER | LOW-GOITER |
| High-paying occupation dummy | -0.3093 | 0.44348 | -0.69028 |
| | (0.45086) | (1.5619) | (0.62258) |
| Canton-specific trend | YES | YES | YES |
| Number of Observations | 474490 | 114016 | 116956 |
| R-squared | 0.0063 | 0.0045 | 0.0089 |
| High-paying occupation dummy | -0.54469 | -0.52011 | -0.76598 |
| | (0.46783) | (1.41248) | (0.68906) |
| Canton-specific trend | NO | NO | NO |
| Number of Observations | 474490 | 114016 | 116956 |
| R-squared | 0.0059 | 0.0044 | 0.0083 |

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%
Coefficients correspond to changes in percentage points.
High-goiter districts are those belonging to the top 25% of the population-weighted goiter distribution.
Low-goiter districts are those belonging to the bottom 25% of the population-weighted goiter distribution.
All regressions include people born in Switzerland in 1900-1944 and interviewed for the 1970 Census.
Standard errors in parentheses, clustered at the canton-year of birth level.

Figure 2.3: Change in occupational characteristics after iodization




(Source: 1970 Swiss Census and England and Kilbourne (1988))

also controls for canton and cohort fixed effects, as well as a canton-specific trend. What is easy to see from figure 2.3 is that whereas people in low-goiter areas had the same mix of characteristics pre- and post-iodization, high-goiter areas saw a decrease in the physical and a corresponding increase in the cognitive component of occupations, signifying a shift towards occupations with higher cognitive demands than before.

Table 2.11 shows results for the sample as a whole of regressing each occupational characteristic on the percentage of iodized salt sales one year prior to birth, controlling for canton and cohort fixed effects, as well as a canton-specific trend. Looking at all areas, there seems to be a slight decrease in physical skills, and a slight increase in cognitive skills. When we only look at high-goiter regions, the coefficients increase both in magnitude and significance, with the exception of manual dexterity and spatial ability. The change is of the order of 0.03 (in absolute value), which, depending on the coefficient, is between 4 and 8% of a standard deviation in the sample. This is a tiny change, but it is significant. Moreover, as in the case of high-paying occupations, results are driven by the effect of iodization on males. This is apparent once we look at Table 2.8, which breaks the sample down by gender. There's a big drop in physical demands (kneeling, climbing, reaching, etc) for females, and a big increase in verbal abilities, but no other characteristic seems affected.

Table 2.7: Occupational characteristics: Coefficient on Iodized Salt 1 year prior to birth, whole sample

| | WHOLE SAMPLE | | |
|---|---|---|---|
| | ALL AREAS | HIGH-GOITER | LOW-GOITER |
| Manual Dexterity | -0.0065267** | -0.0054148 | -0.0055883 |
| | (0.0025958) | (0.007351) | (0.0037123) |
| Motor Control | -0.0019655 | -0.0094397 | -0.0007528 |
| | (0.0023743) | (0.0070648) | (0.0038487) |
| Physical Demands | -0.0093404* | -0.0362085** | 0.006235 |
| | (0.0050766) | (0.0147821) | (0.007376) |
| Strength | -0.0069763 | -0.0283815** | 0.0039593 |
| | (0.0046804) | (0.0133594) | (0.0061834) |
| Spatial Ability | 0.0015487 | -0.0007003 | 0.0058368 |
| | (0.0031976) | (0.0097206) | (0.004653) |
| Numerical Ability | 0.0110898*** | 0.033474*** | 0.0091073* |
| | (0.0035736) | (0.0076685) | (0.004735) |
| Verbal Ability | 0.0107766*** | 0.0270125*** | 0.0060569 |
| | (0.0037826) | (0.0080725) | (0.004766) |
| Intelligence | 0.0107693*** | 0.0221547*** | 0.0086688* |
| | (0.0035202) | (0.0074428) | (0.0045106) |
| Number of observations | 1542006 | 385322 | 377347 |

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%
High-goiter districts are those belonging to the top 25% of the population-weighted goiter distribution.
Low-goiter districts are those belonging to the bottom 25% of the population-weighted goiter distribution.
All regressions include people born in Switzerland in 1900-1944 and interviewed for the 1970 Census.
Standard errors in parentheses, clustered at the canton-year of birth level.

Table 2.8: Occupational characteristics: Coefficient on Iodized Salt 1 year prior to birth, by gender

| | MALES ONLY | | |
|---|---|---|---|
| | ALL AREAS | HIGH-GOITER | LOW-GOITER |
| Manual Dexterity | -0.0085004*** | -0.0083534 | -0.0050923 |
| | (0.0032936) | (0.0085289) | (0.0048492) |
| Motor Control | -0.005372** | -0.0125601* | -0.0007246 |
| | (0.0026382) | (0.0066056) | (0.0043759) |
| Physical Demands | -0.0108344* | -0.0306461* | 0.0074013 |
| | (0.0061104) | (0.0159415) | (0.0088791) |
| Strength | -0.0054226 | -0.026537* | 0.0051245 |
| | (0.0056623) | (0.013511) | (0.0076101) |
| Spatial Ability | 0.0028744 | 0.0018137 | 0.0066139 |
| | (0.0039967) | (0.0116746) | (0.0058114) |
| Numerical Ability | 0.0125323*** | 0.0397279*** | 0.0075499 |
| | (0.0045392) | (0.0093934) | (0.0061012) |
| Verbal Ability | 0.0121351*** | 0.0268816*** | 0.0069954 |
| | (0.0045387) | (0.0095628) | (0.0062836) |
| Intelligence | 0.0124379*** | 0.0230924*** | 0.0094617 |
| | (0.004258) | (0.0087863) | (0.0058803) |
| Number of observations | 1080860 | 274227 | 263677 |
| | FEMALES ONLY | | |
| | ALL AREAS | HIGH-GOITER | LOW-GOITER |
| Manual Dexterity | -0.0032167 | 0.0013695 | -0.006952 |
| | (0.0031127) | (0.0095191) | (0.0043611) |
| Motor Control | 0.0044321 | -0.000404 | -0.0020479 |
| | (0.0048784) | (0.0135774) | (0.0073923) |
| Physical Demands | -0.0083425 | -0.0488137** | 0.0044071 |
| | (0.0077268) | (0.0198685) | (0.0092193) |
| Strength | -.0111087 | -0.0324223 | 0.0038235 |
| | (0.007762) | (0.0201268) | (0.0104108) |
| Spatial Ability | -0.0014131 | -0.0081934 | 0.0070284 |
| | (0.0049119) | (0.0126684) | (0.0067052) |
| Numerical Ability | 0.0087602** | 0.0167783 | 0.0145821** |
| | (0.0044105) | (0.0126285) | (0.0059269) |
| Verbal Ability | 0.0083115 | 0.0256555* | 0.0038328 |
| | (0.0054498) | (0.0145434) | (0.007123) |
| Intelligence | 0.0079433 | 0.01827 | 0.0081388 |
| | (0.0049782) | (0.0149586) | (0.0063557) |
| Number of observations | 461146 | 111095 | 113670 |

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%
High-goiter districts are those belonging to the top 25% of the population-weighted goiter distribution.
Low-goiter districts are those belonging to the bottom 25% of the population-weighted goiter distribution.
All regressions include people born in Switzerland in 1900-1944 and interviewed for the 1970 Census.
Standard errors in parentheses, clustered at the canton-year of birth level.

Table 2.9: Occupational characteristics: Born after iodization, whole sample

| | WHOLE SAMPLE | | | |
|---|---|---|---|---|
| | All cohorts | | Born +/- 10 years from jump | |
| | (1) | (2) | (3) | (4) |
| Manual Dexterity | 0.0040157 | 0.0036855 | 0.0077488* | 0.0071808 |
| | (0.0031435) | (0.0038862) | (0.0045885) | (0.0057727) |
| Motor Control | 0.0006691 | -0.0001699 | 0.0020538 | 0.0019644 |
| | (0.003453) | (0.0040769) | (0.004833) | (0.0056653) |
| Physical Demands | -0.013304* | -0.0220961*** | -0.006845 | -0.0130432 |
| | (0.0069865) | (0.0083442) | (0.0097762) | (0.0125692) |
| Strength | -0.0082357 | -0.0172355** | -0.0102562 | -0.0140808 |
| | (0.0067016) | (0.00785) | (0.0093749) | (0.0108008) |
| Spatial Ability | -0.0026036 | -0.0014481 | 0.0122934** | 0.0084329 |
| | (0.0043484) | (0.0050618) | (0.0060556) | (0.0075997) |
| Numerical Ability | 0.0086838** | 0.0125876*** | 0.017797*** | 0.0174269*** |
| | (0.0033974) | (0.0042332) | (0.0047274) | (0.0057999) |
| Verbal Ability | 0.0065171 | 0.0093804* | 0.0149158*** | 0.0143708** |
| | (0.0040434) | (0.0049353) | (0.005796) | (0.0068862) |
| Intelligence | 0.0037387 | 0.0042264 | 0.0116246** | 0.0085775 |
| | (0.0036296) | (0.0043923) | (0.0049898) | (0.0058129) |
| Number of observations | 1546952 | 1546952 | 655388 | 655388 |

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%

Columns (1) and (3) assume common cohort fixed effects for high- and non-high-goiter districts.

Columns (2) and (4) assume different cohort fixed effects for high- and non-high-goiter districts.

Standard errors in parentheses, clustered at the district-year of birth level.

Table 2.10: Occupational characteristics: Born after iodization, by gender

| | MALES ONLY | | | |
|---|---|---|---|---|
| | All cohorts | | Born +/- 10 years from jump | |
| | (1) | (2) | (3) | (4) |
| Manual Dexterity | 0.0023531 | 0.0030134 | 0.0071247 | 0.0084666 |
| | (0.0038217) | (0.0046336) | (0.0054618) | (0.0065581) |
| Motor Control | -0.0025219 | -0.0025243 | -0.0003748 | -0.0017929 |
| | (0.0035052) | (0.0041845) | (0.0049609) | (0.005474) |
| Physical Demands | -0.0125781 | -0.0190955* | -0.0114189 | -0.0108484 |
| | (0.0083503) | (0.0097889) | (0.0112654) | (0.0142136) |
| Strength | -0.0046247 | -0.0142717* | -0.0138346 | -0.0130591 |
| | (0.0075081) | (0.0086543) | (0.0098678) | (0.0113806) |
| Spatial Ability | -0.0006729 | 0.0004197 | 0.0149853** | 0.0167077* |
| | (0.0051193) | (0.0058652) | (0.0072967) | (0.0085963) |
| Numerical Ability | 0.0127004*** | 0.0163939*** | 0.0241815*** | 0.0263489*** |
| | (0.0041941) | (0.0051006) | (0.0054625) | (0.0067043) |
| Verbal Ability | 0.0091454* | 0.0095034 | 0.0196572*** | 0.019442** |
| | (0.0048549) | (0.0058286) | (0.0064798) | (0.0077836) |
| Intelligence | 0.0074831* | 0.0050152 | 0.0157109*** | 0.014659** |
| | (0.0042551) | (0.0050422) | (0.0055496) | (0.0066602) |
| | FEMALES ONLY | | | |
| | All cohorts | | Born +/- 10 years from jump | |
| | (1) | (2) | (3) | (4) |
| Manual Dexterity | 0.0064285 | 0.0073436 | 0.0085276 | 0.007532 |
| | (0.0044443) | (0.0056172) | (0.0066839) | (0.0074156) |
| Motor Control | 0.0060262 | 0.0048897 | 0.010965 | 0.0111891 |
| | (0.0059711) | (0.0072029) | (0.0084836) | (0.0099415) |
| Physical Demands | -0.0197688* | -0.0209538 | 0.0025781 | -0.0097583 |
| | (0.0115914) | (0.0141631) | (0.0156304) | (0.0185495) |
| Strength | -0.0188164* | -0.0159859 | -0.005453 | -0.0066519 |
| | (0.0110188) | (0.013405) | (0.0156243) | (0.0179133) |
| Spatial Ability | -0.0096534 | 0.0012857 | 0.0026633 | -0.001783 |
| | (0.0065412) | (0.008028) | (0.00846) | (0.009888) |
| Numerical Ability | -0.0017882 | 0.0058379 | -0.0001548 | -0.0005088 |
| | (0.0059043) | (0.0071167) | (0.0087851) | (0.0095157) |
| Verbal Ability | 0.0010073 | 0.0080343 | 0.001617 | 0.0025178 |
| | (0.0069625) | (0.0084891) | (0.0108522) | (0.0117831) |
| Intelligence | -0.0053049 | 0.0040373 | -0.0005824 | -0.0023293 |
| | (0.0066161) | (0.0080397) | (0.0100097) | (0.0104068) |
| Number of observations | 462336 | 462336 | 194259 | 194259 |

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%
Columns (1) and (3) assume common cohort fixed effects for high- and non-high-goiter districts.
Columns (2) and (4) assume different cohort fixed effects for high- and non-high-goiter districts.
Standard errors in parentheses, clustered at the district-year of birth level.

Table 2.11: Occupational characteristics: Fuzzy Regression Discontinuity, whole sample

| | WHOLE SAMPLE | | |
|---|---|---|---|
| | ALL AREAS | HIGH-GOITER | LOW-GOITER |
| Manual Dexterity | -0.0009472 | 0.0041189 | -0.0024479 |
| | (0.0028367) | (0.0118249) | (0.0039328) |
| Motor Control | 0.0000163 | -0.0024329 | -0.0007358 |
| | (0.0025496) | (0.008796) | (0.0038433) |
| Physical Demands | -0.0076898 | -0.0532868** | 0.0066527 |
| | (0.0058905) | (0.0211891) | (0.0079619) |
| Strength | -0.0040244 | -0.0363888** | 0.0057858 |
| | (0.0055137) | (0.0174469) | (0.0067376) |
| Spatial Ability | -0.0011264 | -0.0008482 | 0.004219 |
| | (0.0036201) | (0.013549) | (0.0049332) |
| Numerical Ability | 0.0035306 | 0.0294672*** | 0.0045859 |
| | (0.0042218) | (0.0101903) | (0.0045452) |
| Verbal Ability | 0.0003645 | 0.0258381** | 0.001003 |
| | (0.004452) | (0.0107883) | (0.0048576) |
| Intelligence | -0.0009932 | 0.0129775 | 0.0033626 |
| | (0.0040607) | (0.0091739) | (0.0043635) |
| Number of observations | 1542006 | 385322 | 377347 |

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%
High-goiter districts are those belonging to the top 25% of the population-weighted goiter distribution.
Low-goiter districts are those belonging to the bottom 25% of the population-weighted goiter distribution.
All regressions include people born in Switzerland in 1900-1944 and interviewed for the 1970 Census.
Standard errors in parentheses, clustered at the canton-year of birth level.

Table 2.12: Occupational characteristics: Fuzzy Regression Discontinuity, by gender

| | MALES ONLY | | |
|---|---|---|---|
| | ALL AREAS | HIGH-GOITER | LOW-GOITER |
| Manual Dexterity | -0.0030607 | 0.0053442 | -0.0026801 |
| | (0.0035813) | (0.0140892) | (0.0050988) |
| Motor Control | -0.003096 | -0.0086938 | -0.0013496 |
| | (0.0029474) | (0.0098406) | (0.0045082) |
| Physical Demands | -0.0092432 | -0.0439352* | 0.0055413 |
| | (0.0070682) | (0.0246903) | (0.0097755) |
| Strength | -0.000927 | -0.0306259* | 0.006546 |
| | (0.0064875) | (0.0174439) | (0.00822) |
| Spatial Ability | -0.0006293 | 0.0129399 | 0.0042163 |
| | (0.0048196) | (0.0183486) | (0.0062829) |
| Numerical Ability | 0.0049506 | 0.041329*** | 0.0030917 |
| | (0.0053631) | (0.0128449) | (0.0058297) |
| Verbal Ability | 0.0002278 | 0.0331184*** | 0.0018294 |
| | (0.0052992) | (0.0118991) | (0.0064191) |
| Intelligence | -0.0008748 | 0.0221407** | 0.0035545 |
| | (0.004987) | (0.0106555) | (0.0058077) |
| Number of observations | 1080860 | 274227 | 263677 |
| | FEMALES ONLY | | |
| | ALL AREAS | HIGH-GOITER | LOW-GOITER |
| Manual Dexterity | 0.0040697 | 0.0060009 | -0.002506 |
| | (0.0035782) | (0.0144809) | (0.0046641) |
| Motor Control | 0.0088829 | 0.0132889 | 0.0007584 |
| | (0.0055917) | (0.0190334) | (0.0077163) |
| Physical Demands | -0.0030604 | -0.0587841** | 0.0073969 |
| | (0.0090979) | (0.0236899) | (0.0100802) |
| Strength | -0.011987 | -0.0324252 | 0.0024774 |
| | (0.0095886) | (0.0290438) | (0.011036) |
| Spatial Ability | -0.0031325 | -0.0160187 | 0.0055695 |
| | (0.00581) | (0.0155782) | (0.0071093) |
| Numerical Ability | -0.0008476 | 0.0087092 | 0.0096535 |
| | (0.004911) | (0.0168866) | (0.0060933) |
| Verbal Ability | -0.0005356 | 0.0088448 | -0.0008637 |
| | (0.0061051) | (0.0193026) | (0.0074627) |
| Intelligence | -0.0021015 | -0.0023815 | 0.0034093 |
| | (0.0057062) | (0.0206379) | (0.0067172) |
| Number of observations | 461146 | 111095 | 113670 |

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%

High-goiter districts are those belonging to the top 25% of the population-weighted goiter distribution.

Low-goiter districts are those belonging to the bottom 25% of the population-weighted goiter distribution.

All regressions include people born in Switzerland in 1900-1944 and interviewed for the 1970 Census.

Standard errors in parentheses, clustered at the canton-year of birth level.

Tables 2.9 and 2.10 show the results of regressing occupational characteristics on an indicator variable for belonging to the treatment group (born in a high-goiter district after a jump in iodized salt sales) and other covariates. There are cohort fixed effects which are allowed to be both common across all districts and different for high-goiter districts and the rest of the country. As in the case of table 2.5, which was the equivalent of table 2.9 when I used a high-paying occupation dummy as the outcome of interest, the results here are weaker than in tables 2.7 and 2.8, and for most characteristics the average value of a significant coefficient is between 0.011 and 0.022. However, the general results are the same: positive coefficients are related to cognitive skills, whereas negative coefficients correspond to physical skills. These results are strong for males (table 2.10), especially when I limit the sample to those born within ten years of the intervention. As in the previous table, females don't seem affected, although there is some evidence of a decrease in the physical demands and strength requirement of the occupation that they select into.

Results from the fuzzy regression discontinuity exercise appear on tables 2.11 and 2.12. The values of coefficients for the high-goiter group are somewhat larger in absolute value compared to those in tables 2.7 and 2.8, especially for physical skills, and for the results on males born in high-goiter districts (Table 2.12). Coefficients on occupational characteristics change by 0.025-0.053 points, or 7.2% of a standard deviation in the case of physical demands. There is a big decrease in the physical demands component for females (table 2.12), which goes down by 0.06 points, more than 8% of a standard deviation.

To summarize, the mix of occupational characteristics shifted slightly towards a bigger cognitive component for those cohorts born after iodization in previously highly-deficient areas. The shift was very small -accounting at most for about 8% of a standard deviation- but it was significant. The effect is stronger for males than for females, but as discussed above, female labor market participation was very limited and possibly non-random over that period, so the results on females are harder to interpret.

## 2.9 Concluding remarks

The Swiss Iodization Campaign was the first major nutritional intervention, and many others, such as milk fortification with vitamin D, followed. Yet its effects on economic outcomes have never been studied before. The effects of correcting iodine deficiency on cognition had real and significant effects for the populations treated. The cost-effectiveness of providing universal prophylaxis with iodized salt is indisputable, even if one only takes into account the lower hospitalization costs of people with thyroid disorders, without factoring in the big impact on the economy that increased cognition might have in a population.

Apart from an policy impact evaluation, though, the Swiss Iodization Campaign can also be viewed as an experiment of what happens to a given country and a given population within that country when there is an arguably exogenous change in its cognitive ability. Indeed, one can view iodine deficiency eradication as an "injection of IQ" in the population[8].

Once one thinks about iodization in that light, new and interesting empirical questions pop up. For example, it is usually very hard to de-couple innate ability from schooling when measuring the returns to education in a population, because there is usually not enough variation in the data, as presumably people of low ability do not achieve high education levels, whereas most high-ability people do (for a discussion of this issue, see Heckman and Vytlacil (2001)). In the case of iodization interventions, however, we are faced with a change in overall ability in the population for all levels of schooling, so we are already one step further in solving that problem. It is still a complex issue, however, since one would have to make assumptions about the initial distribution of ability in the population prior to the intervention, and how it changed after the correction. Average observed ability could increase either by a shift of the ability distribution to the right, or by a decrease of its left tail, however the implications for the interpretation of the findings would be different in each case, so would be our capacity to de-couple ability from schooling.

Another question arises from treating iodization in a given population as resulting in a shift of its comparative advantage, as workers select into more cognitive-demanding occupations. This can have implications for the local economy (which we can treat as open), as well as the economy of the country as a whole. For example, do we observe worker migration into other areas, and if yes, what is the profile of the workers who migrate and of the receiving regions? How are local and countrywide relative wages affected? These are intriguing questions which could be answered by looking at the various iodization interventions that have taken place around the world, starting with the Swiss and North American experience of the 1920s.

Tremendous steps have been taken for the global eradication of iodine deficiency in the past 20 years, but there is still a long way to go before nobody is affected by iodine deficiency disorders. Given the obvious cost-effectiveness of universal salt iodization, and the beneficial impacts for the treated populations as they were estimated in this paper, it should be clear that eradicating iodine deficiency should be at the top list of priorities for governments and health-promoting organizations.

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[8] I thank Prof. Yona Rubinstein who came up with this graphic expression.

# Chapter 3

# The Economic Effects of Micronutrient Deficiency: Evidence from Salt Iodization in the United States[1]

## 3.1 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.[2] 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 turned to the historical experience of currently developed countries in order to estimate the potential benefits of health interventions.[3]

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,

[1]This chapter represents co-authored work with David N. Weil (Brown University) and James Feyrer (Dartmouth College).

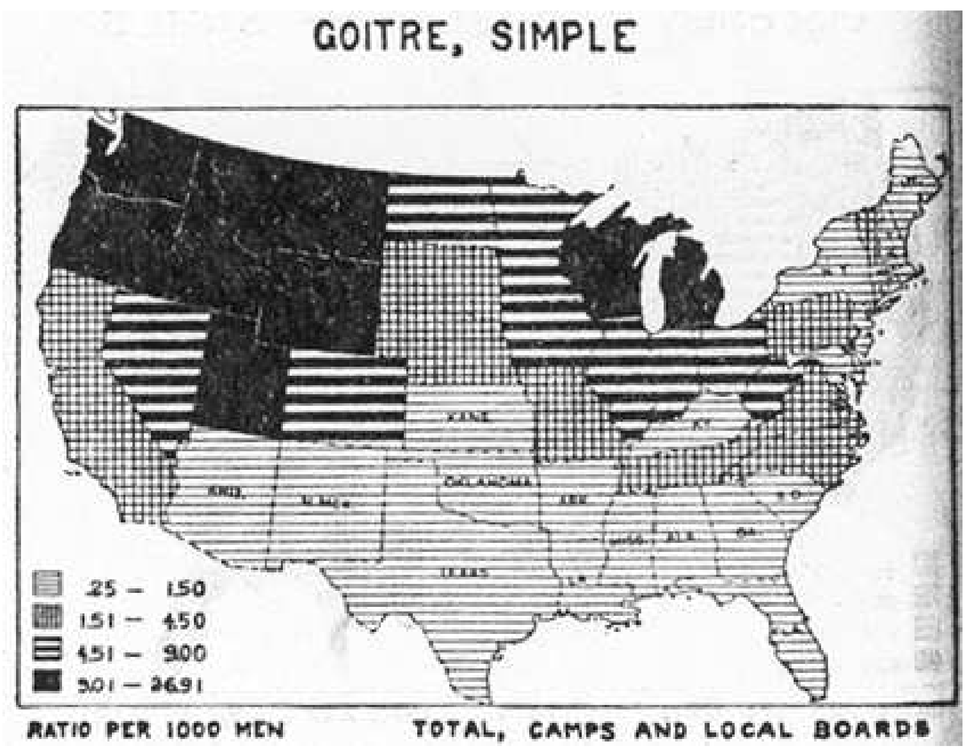
[2]For instance, Sachs (2003) shows that efforts to eliminate malaria have substantial effects on income, through their effect on health, reduced absenteeism, etc. Acemoglu and Johnson (2007) look at the effect of health interventions and find little effect. Weil (2007) charts a middle course.

[3] 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.

long-run effects of such interventions on either population health or economic measures such as labor productivity.[4] 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 3.1 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.

Figure 3.1: Distribution of Goiter during WWI




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

[4]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.

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.

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 3.2 provides some background on iodine deficiency disorders. Section 3.3 outlines the history of salt iodization in the US. Section 3.4 describes our data and provides some background on their collection. Section 3.5 explains our identification strategy and section 3.6 presents our results. Section 3.7 interprets our results and puts them in the context of related research on the effects of iodization. Section 3.8 concludes.

## 3.2 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. Childhood height, which depends, among other factors, on the environment in utero and maternal health during pregnancy, is a significant predictor of both the performance in cognitive tests at a young age, and also of adult earnings (Case and Paxson 2008).

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 et al., 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 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].

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

[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.

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 region 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 et al. 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

[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.

[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.

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].

## 3.3 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 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

[11] Iodization of water supplies proved wasteful since only a small proportion of water is used 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 Marine and O.P. Kimball. For details see Marine and Kimball (1921), and Carpenter (2005).

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].

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 3.2 and 3.3 shows two ads from this period. Figure 3.4 is a copy of a newspaper clipping from the era.

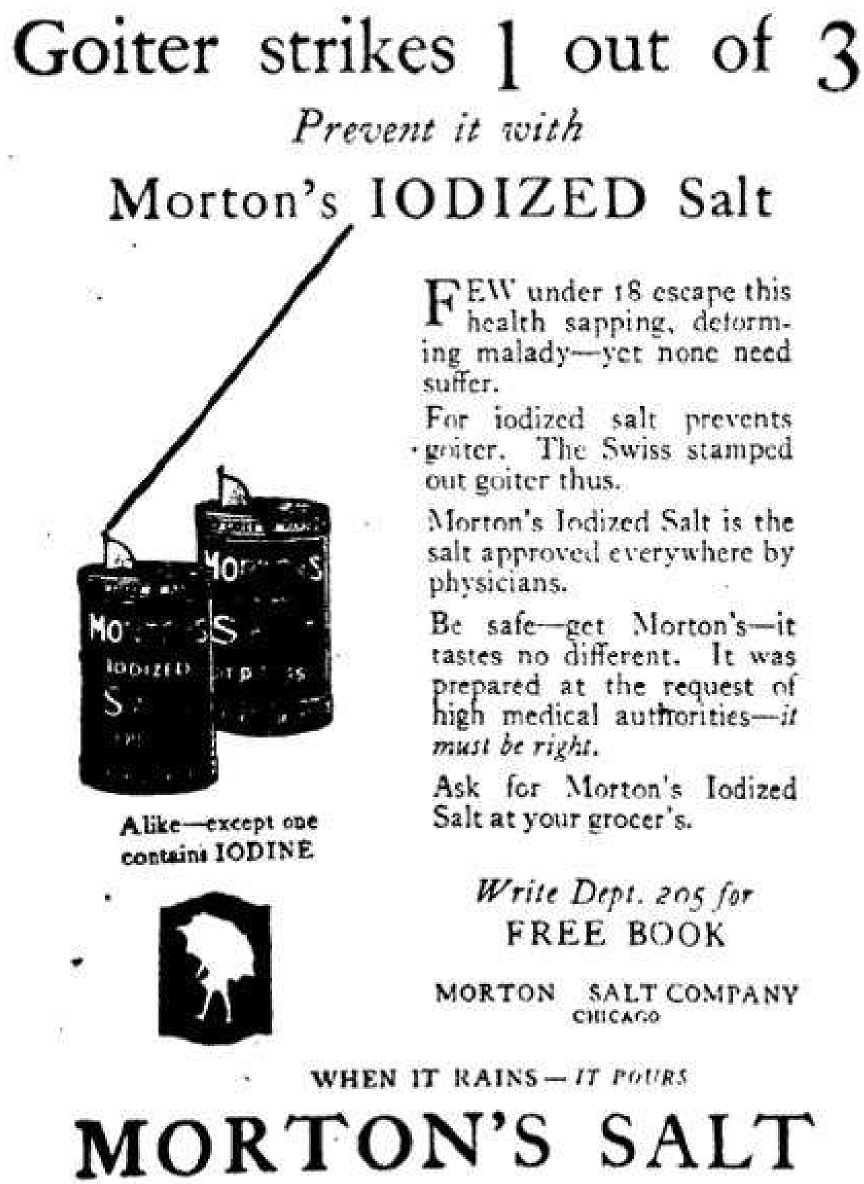
After Michigan introduced iodized salt, the penetration of the new product statewide was quite rapid. As mentioned above, salt producers made the new product available nationwide, since this

[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.

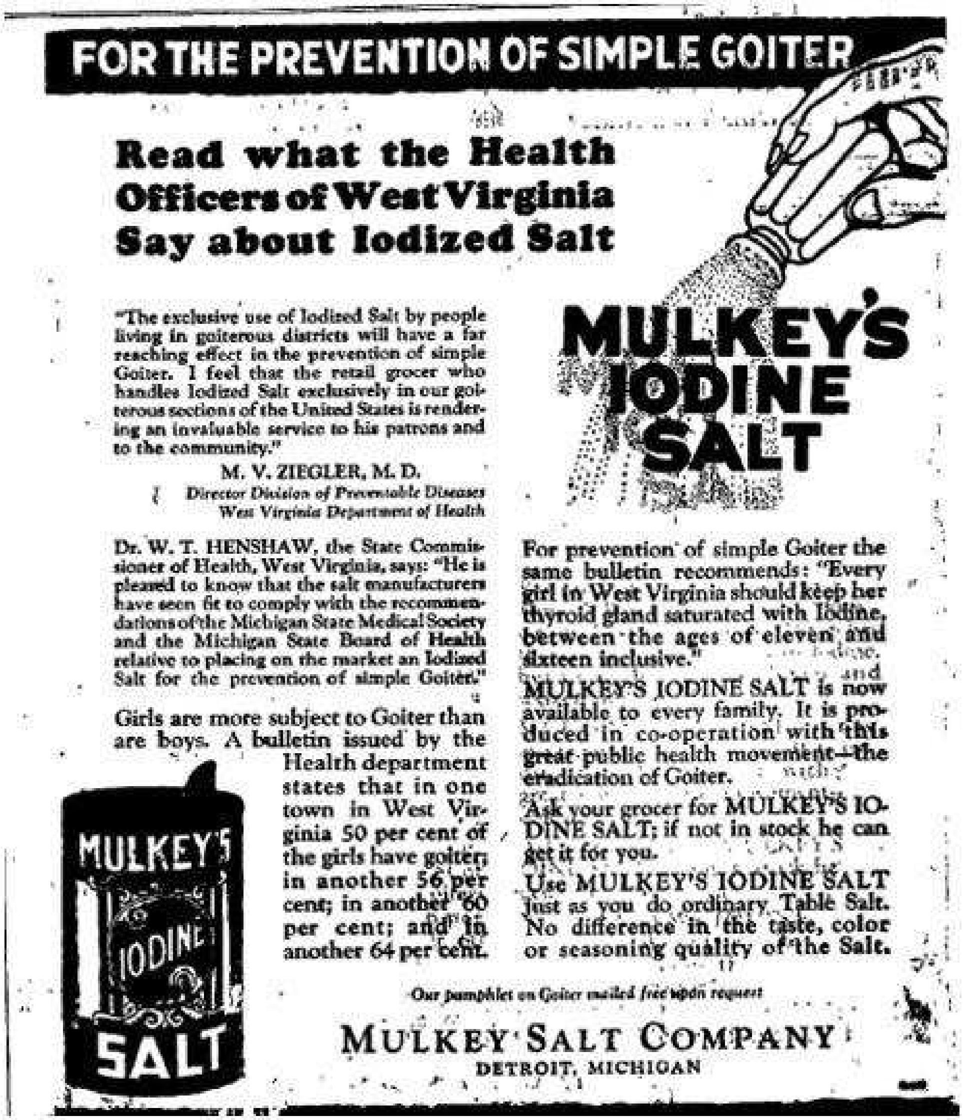
[15]Salt production takes three forms: evaporated, rock salt, and the production of liquid brine. In 1924 the quantities produced by these three methods were 2.22, 2.06, and 2.51 million short tons, respectively. Brine was used exclusively as a feedstock by the chemical industry. According to the Salt 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).

Figure 3.2: Ads for Iodized Salt




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

Figure 3.3: Ads for Iodized Salt




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

Figure 3.4: 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. Kelster 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 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 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.

### 3.3.1 Evidence from mortality data

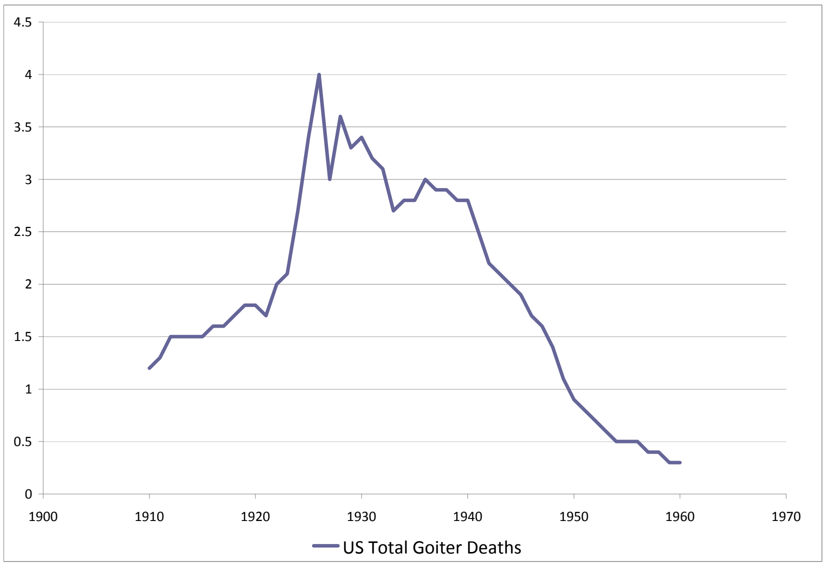
A second source for evidence on the spread of iodized salt comes from data on mortality from thyroid disease. Mortality data provides a good indicator of iodization because, as discussed above, the treatment designed to help goiter sufferers sometimes ended up killing them. The doctors and public health 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 (1934a) and Carpenter (2005)].

Figure 3.5 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

[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 3.5: US Deaths from exophthalmic goiter, 1920-1960

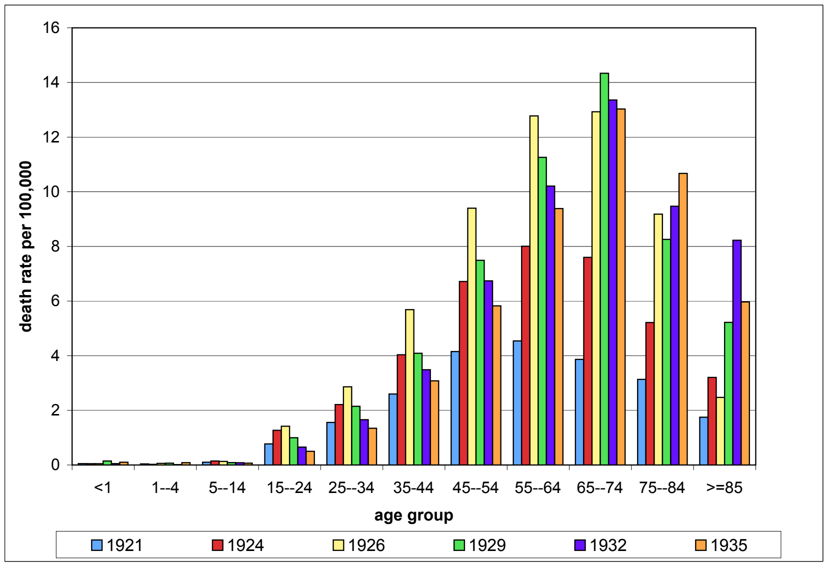



this period. Exophthalmic goiter is an enlargement of the thyroid accompanied by bulging of the eyes, which is sign of hyperthyroidism [18]. There is an extremely large rise in the death rate at the time of iodization: from 2.1 per 100,000 in 1923 to 2.7 in 1924, 3.4 in 1925, and 4.0 in 1926. Deaths 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 1934b).

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. As figure 3.6 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

[18] 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.

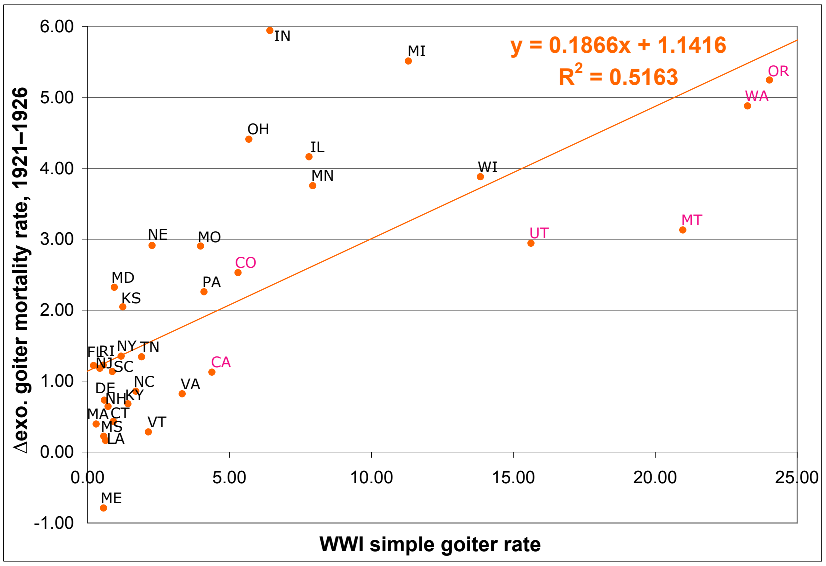
Figure 3.6: US goiter deaths by age group, 1921-1935




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 3.7 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 3.8 shows annual data on thyroid disease death rates for Michigan along with the other 10 states in the upper right quadrant of Figure 3.7. 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.

Figure 3.7: Changes in thyroid mortality vs. pre-existing goiter rates, 1921-1926



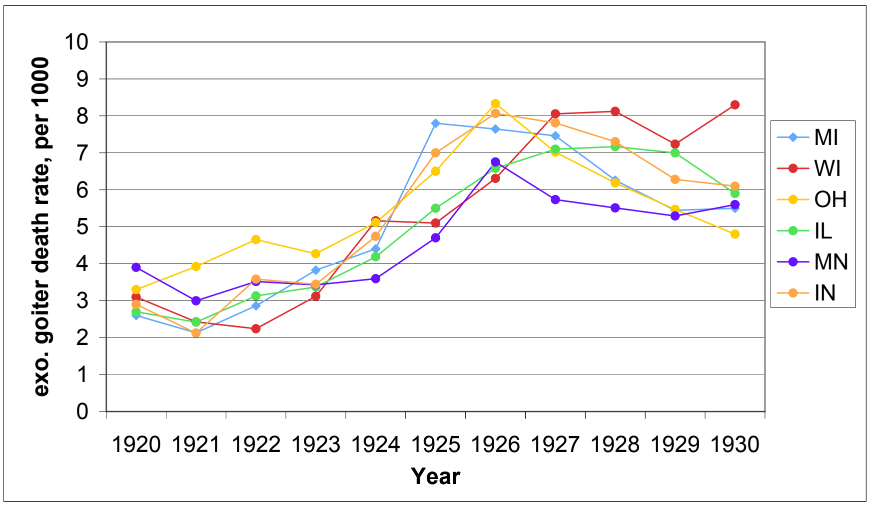

## 3.4 Data Sources

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.

Figure 3.8: Deaths from exophthalmic goiter, Michigan and other states, 1920-1930



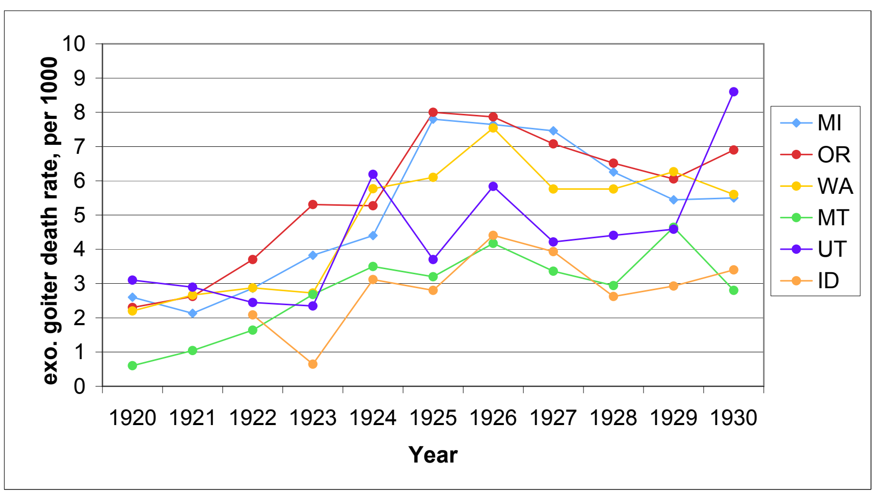



Figure 3.9: Sections from *Defects Found in Drafted Men*

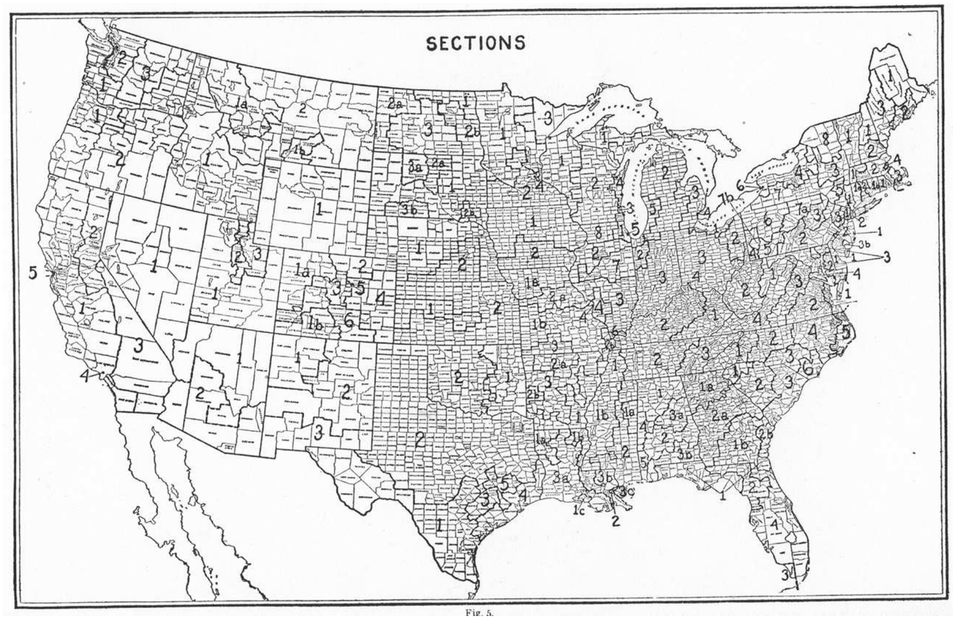



Fig. 5.

### 3.4.1 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 3.9 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 3.10 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

[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 3.10: 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 | .56 |
| 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 3.11: Histogram of Section Level Simple Goiter Rates from *Defects Found in Drafted Men*

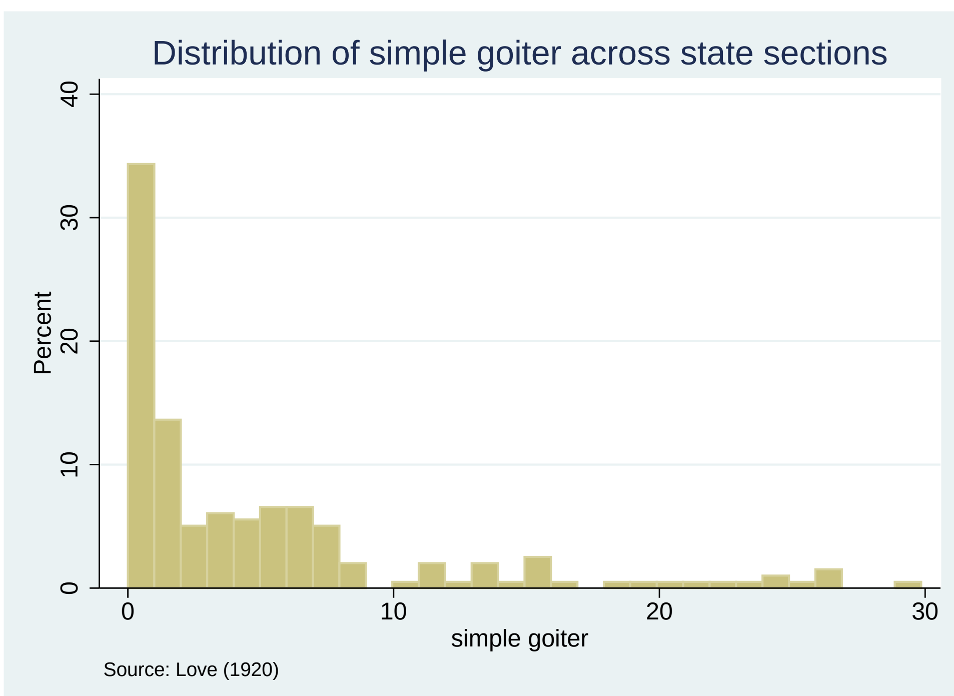
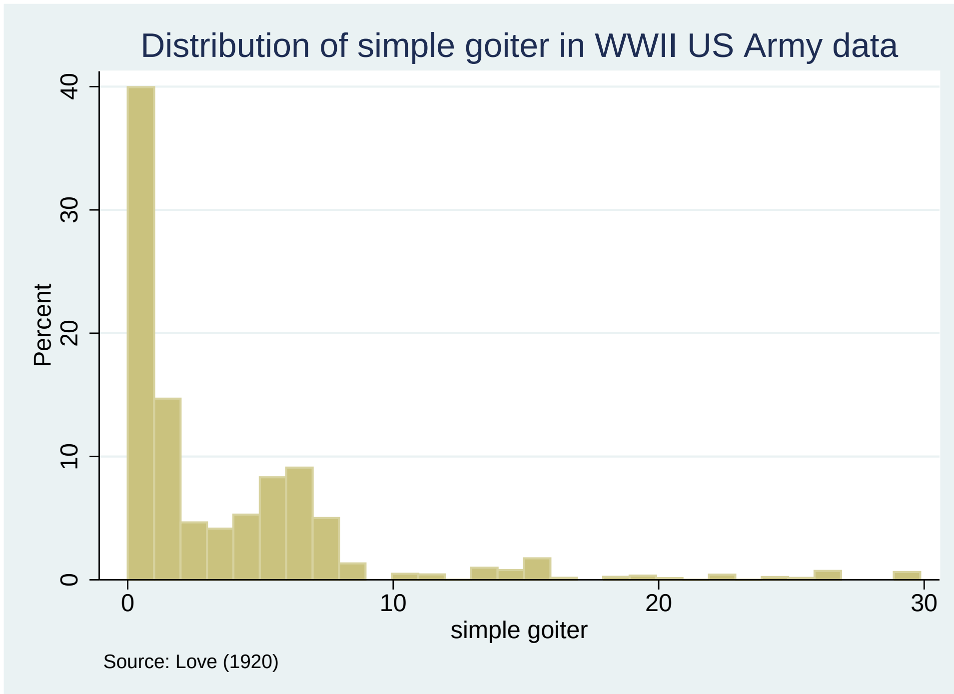


Figure 3.12: Histogram of Population Goiter Rates from *Defects Found in Drafted Men*




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 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 3.13 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:

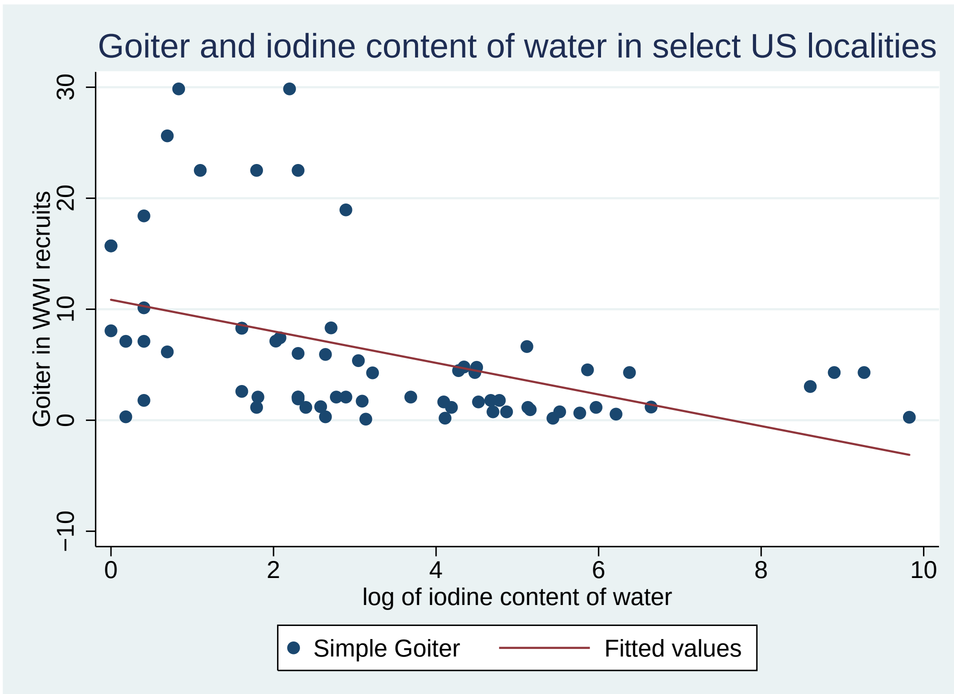
[21] Professor of Physiologic Chemistry at the University of Minnesota Medical School.

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

$$\text{simple goiter} = \underset{(1.445)}{10.854} - \underset{(0.355)}{1.422} \times \text{log iodine}$$

(Standard errors in parentheses, N=67)

Figure 3.13: McClendon's data on the iodine content of water




source: McClendon (1924)

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.

### 3.4.2 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. 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.

### 3.4.3 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 described in Table 3.2[23].

[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 3.1: 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** |

Table 3.1 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.

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].

Table 3.2: 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 |

### 3.4.4 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].

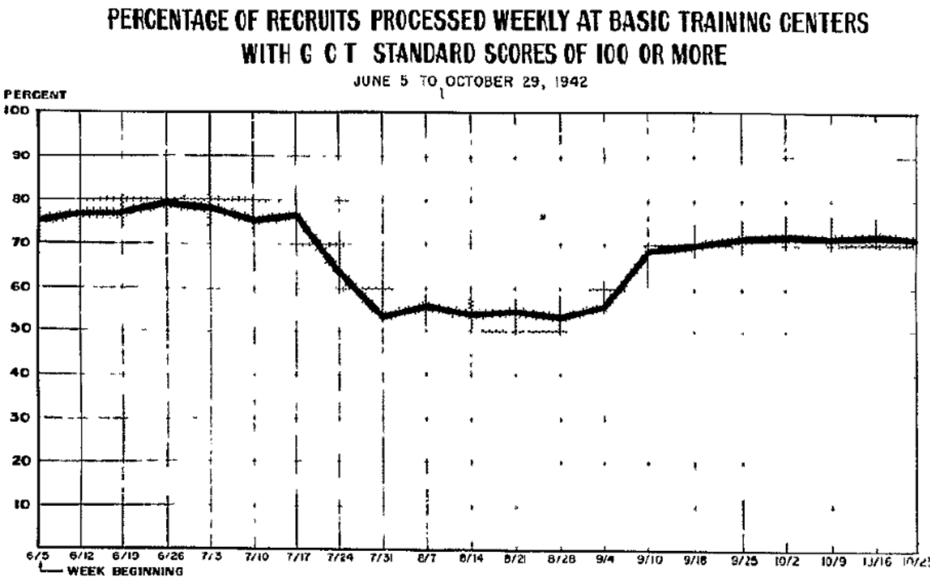
The AAF fought back against this change by using a second test, the mechanical aptitude (MA)

[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.

Figure 3.14: 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.

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. (1948)].

Figure 3.14 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

[27]ibid, p.56.

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, 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 3.15 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 3.1, this was also a period in which very few recruits were entering the AAF – this histogram is based on only 384 recruits.

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 3.3 and Figure 3.16 give the proportion of high school graduates in each branch by birth year. Figure 3.17 shows the proportion of high-school graduates by enlistment month, separately for the Airforce and the rest of the Army.

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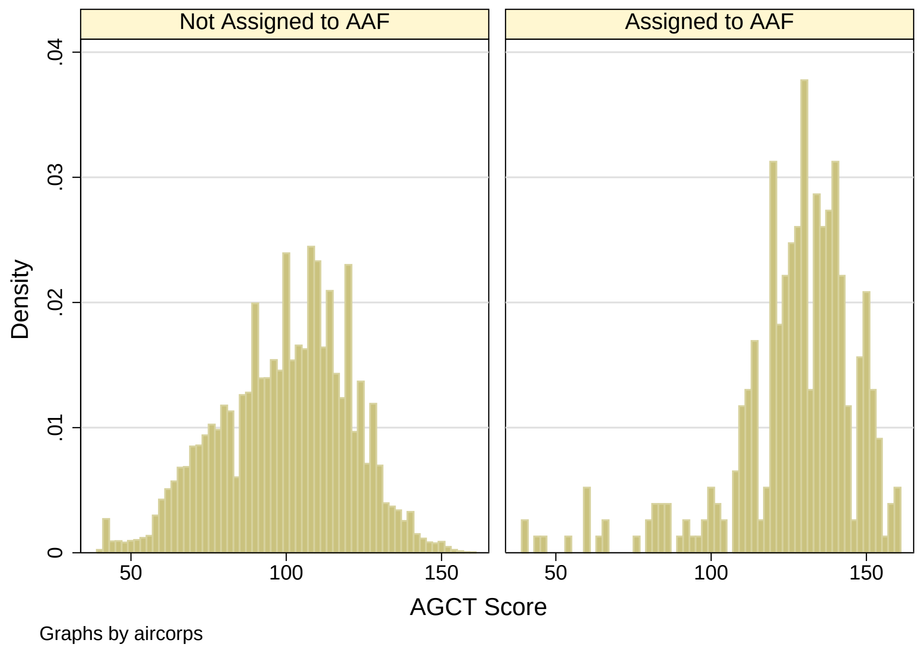
[28] We are grateful to Joseph Ferrie for making us aware of this data.

[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.

[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.

Figure 3.15: AGCT Scores for AAF versus all enlistees

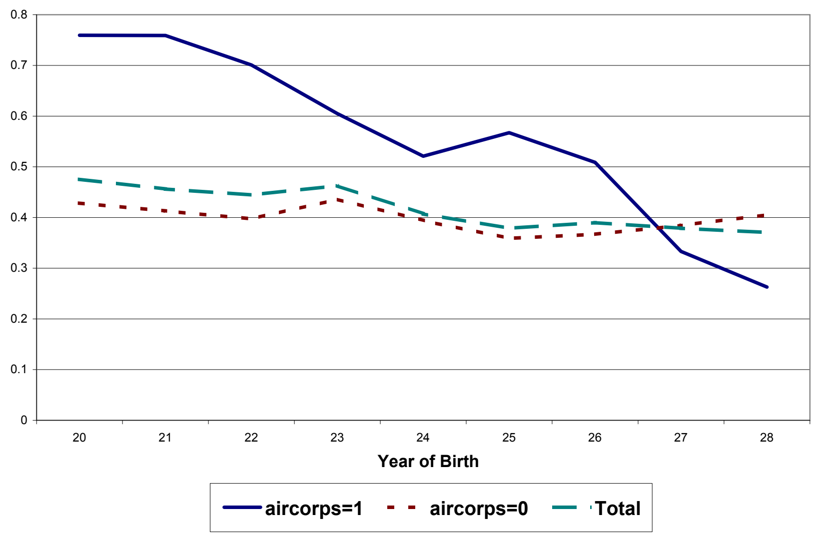



source: WWII enlistment records.

Table 3.3: 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 3.16: High-School Graduation Rates by birth year

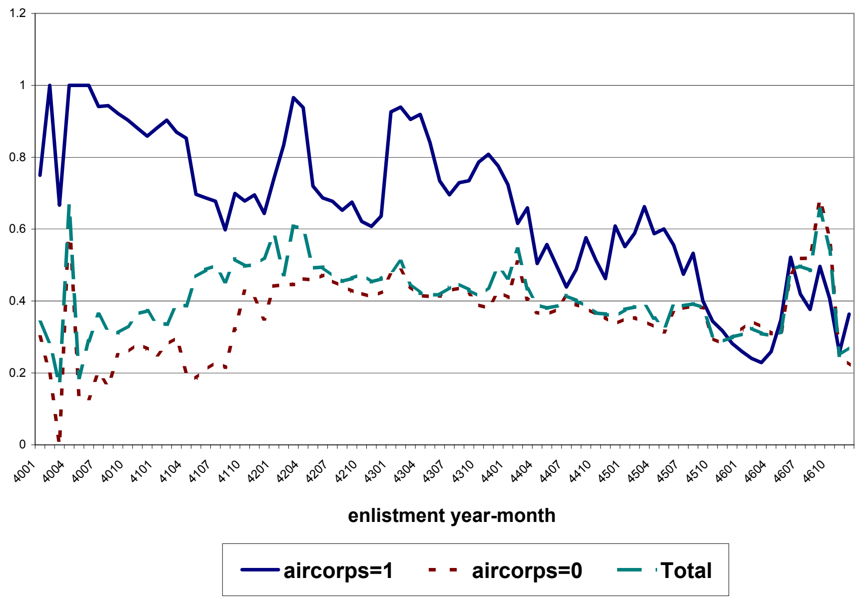



As expected, Table 3.3 and Figure 3.16show that the younger cohorts were less likely to have a high-school degree than the older cohorts. It is also clear that there was positive selection into the Airforce, which became less and less pronounced over the course of the war. By the time the 1927 and 1928 cohorts enlisted, the Ground Forces were getting equally, if not better-qualified recruits than the Air Forces. Figure 3.17 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 3.17 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 3.17 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 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

Figure 3.17: High-School Graduation Rates by enlistment month




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].

## 3.5 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

[31]See Appendix 3.A for the details of these calculations.

1924 are post-treatment.

The basic regression specification is:

$$y_i = \alpha + \sum_{t \neq 1924} \beta_t [goiter \times I(t = birthyear)] + Controls + \epsilon \qquad (3.5.0.1)$$

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 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.

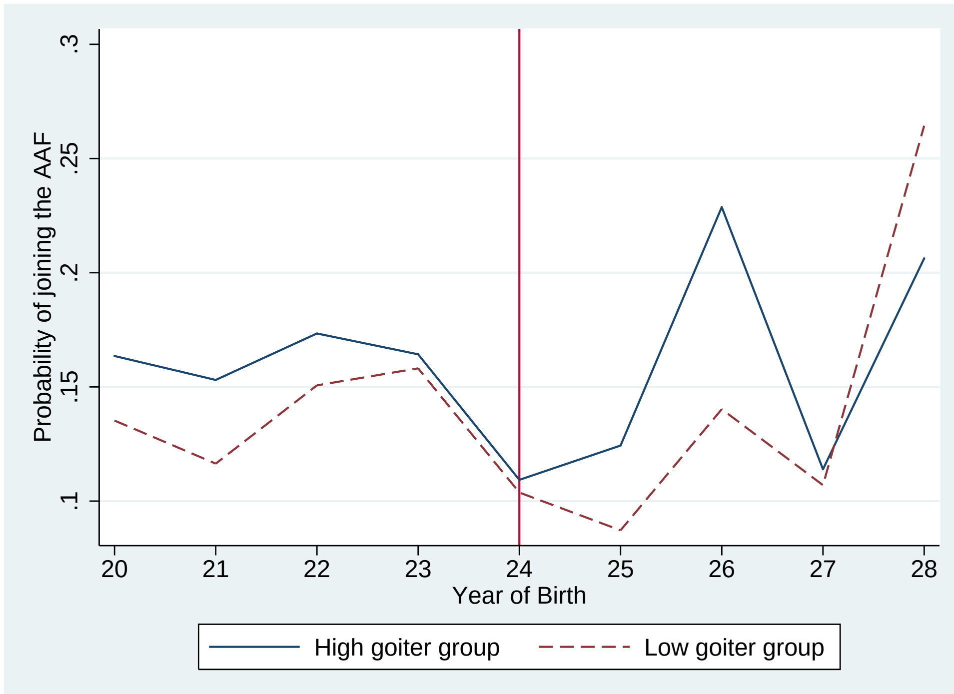
Since we have many observations utilizing a single section level data point for the goiter level we cluster our standard errors at the *Defects* section level.

## 3.6 Results

Figure 3.18 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 3.18 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.

[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 3.18: Probability of joining the Airforce




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 3.19. Figure 3.19 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 birth year separately, so we ran 9 regressions for this graph). Figure 3.19 tells the same story as Figure 3.18, but it's more convincing, because it accounts for the effect of enlisting in any particular month over the course of the war. Figure 3.19 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 3.19 also shows the *negative* selection into the Airforce for the 1928 cohort, who enlisted during the final phase of the war.

### 3.6.1 Linear Probability Model of joining the AAF

Table 3.4 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

Table 3.4: 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 |

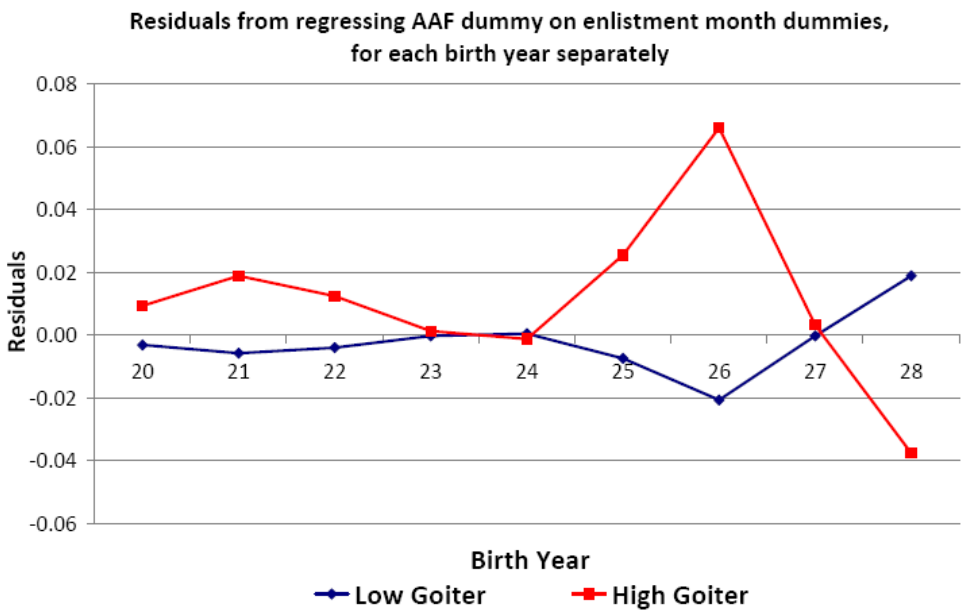
* significant at 5%; ** significant at 1%
All regressions clustered at the state-section level
Regressions (1) and (3) - white men enlisted in the period 1940-1946
Regressions (2) and (4) - white men enlisted in the period July 1940- December 1946

Table 3.5: 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 3.19: 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

two columns of the table we include goiter trend (defined as the section goiter rate interacted with year of birth) 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 3.3 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 3.5 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

Table 3.6: 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

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.

### 3.6.2 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 3.6 and 3.7. Table 3.6 lists results of the interaction of goiter in the *Defects* section of origin and birth year dummies, whereas Table 3.7 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

Table 3.7: 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 3.8: 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

always see a jump in the coefficients for those cohorts born in 1925 and 1926, after salt iodization.

Table 3.8 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.

### 3.6.3 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 3.4. Table 3.9 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 3.4, would cast doubt on our results from the previous regressions.

As can be seen from Table 3.9, 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 check of our results. Hemophilia, multiple sclerosis, acromegaly, and tabes dorsalis are very

Table 3.9: 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 3.10: 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.

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 3.10 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.

## 3.7 Interpretation

How large are these effects? The highest goiter places have goiter rates of 30. The coefficients (from Table 3.4) suggest that about 15% more recruits from the highest goiter regions go into the AAF after salt iodization. From Appendix 3.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.

## 3.8 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.

## 3.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.

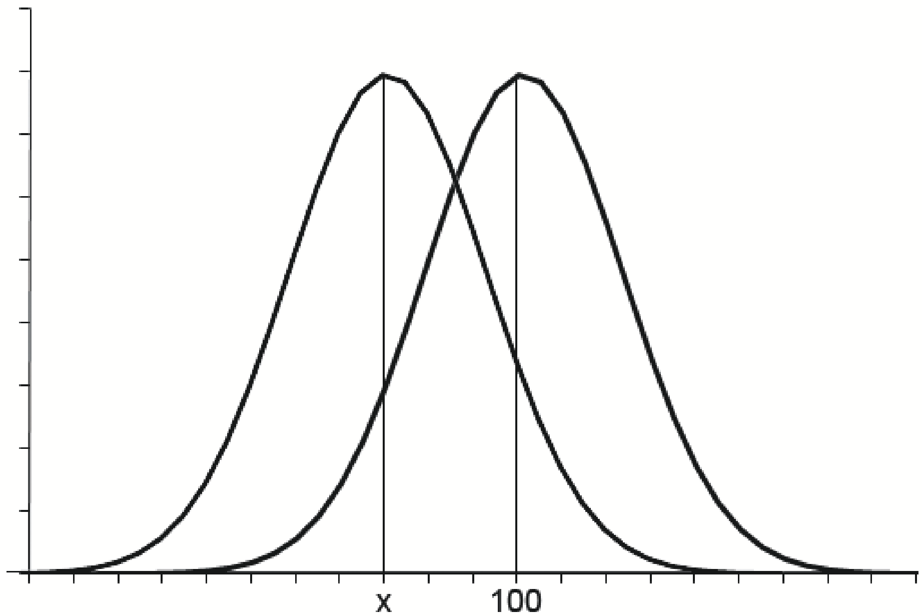
## 3.B Interpretation of the coefficients: What was the IQ increase following iodization?

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 3A-1).

Let $\alpha$ 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

Figure 3A-1: Shift in the IQ distribution of high-goiter areas after iodization




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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