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Abstract

This paper examines the impact of salt iodization in Switzerland in the 1920s and 1930s on schooling outcomes. Iodine deficiency in utero causes mental retardation, and correcting the deficiency is expected to increase the productivity of a population by increasing its cognitive ability. The exogenous increase in cognitive ability brought about by the iodization program is also useful in the context of disentangling the effects of innate ability and education in later-life outcomes. I identify the impact of iodization in three ways: first, in a differences-in-differences framework, I exploit geographic variation in iodine deficiency, as well as the fact that the nationwide campaign to decrease iodine deficiency began in 1922. Second, I use spatial and temporal variation in the introduction of iodized salt across Swiss cantons, and examine whether the level of iodized salt sales at the time of one's birth affected one's educational attainment. Third, I employ a fuzzy regression discontinuity design and use jumps in sales of iodized salt across Swiss cantons to identify the effect of iodization, by comparing outcomes for those born right before and right after these sudden changes in the treatment environment. These approaches indicate that the eradication of iodine deficiency in previously deficient areas increased the schooling of the population significantly. The effects are larger for females than for males, which is consistent with medical evidence showing that women are more likely to be affected by iodine deficiency disorders than men.

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"Quodque magis mirum, sunt qui non corpora tantum Verum animos etiam valeant mutare liquores."

"And what is more wonderful, there are waters that have the power to change not only the body but also the mind."

Ovid, Metamorphoses, lib. XV., 317-318. [Taken from Langer (1960)]

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).

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

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

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

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

[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.

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 2 provides a short review of the relevant literature from Economics. Section 3 provides some background on iodine deficiency disorders, and section 4 describes the campaign for salt iodization in Switzerland. Section 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 6 introduces additional data, which show the decline in deaf-mutism following the introduction of iodized salt. Sections 7, 8, and 9 describe the identification strategy and contain the empirical findings. Section 10 provides an interpretation of the results, and section 11 concludes.

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

[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.

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.

In a recently published paper, Erica Field, Omar Robles, and Maximo Torero study the effects of iodine deficiency on educational attainment in Tanzania (Field, Robles and Torero 2009). Theirs is the first published paper to link economically significant outcomes to iodine deficiency, and it supports the idea of improved schooling outcomes after iodine supplementation. Interestingly, Field et al. also find bigger effects for females, which could be due either to biological differences or differences associated with intra-household resource allocation and social responses to increased cognition of males and females. My paper is different than theirs in a number of ways: first, enough time has passed since the intervention in Switzerland to allow for the estimation of the total impact and long-run effects of iodine deficiency eradication on human capital accumulation. Second, iodized salt was introduced in Switzerland before the link between iodine intake in utero and cognitive ability was established. This makes it far less likely that selection into treatment affects my estimates. Salt iodization also happened at a time when food trade was much more limited than today, so that consuming iodine-rich food in an iodine-poor area was not very likely. Finally, although it affected different areas at different times, the introduction of iodized salt represented a wide-reaching public health campaign which affected all areas of the country. This, in conjunction with the fact that the importance of iodine supplementation was not fully realized at the time, make it unlikely that selective migration in order to receive treatment might have biased the results. To sum up, although non-experimental, the particulars of the intervention in Switzerland, together with the substantial pre-existing geographic variation in the prevalence of iodine deficiency, provide me with natural treatment and control groups and with a research design which allow for the study of the long-term impact of iodine deficiency on human capital accumulation and productivity.

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

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

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 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

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

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

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 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

[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.

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).

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

[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.

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

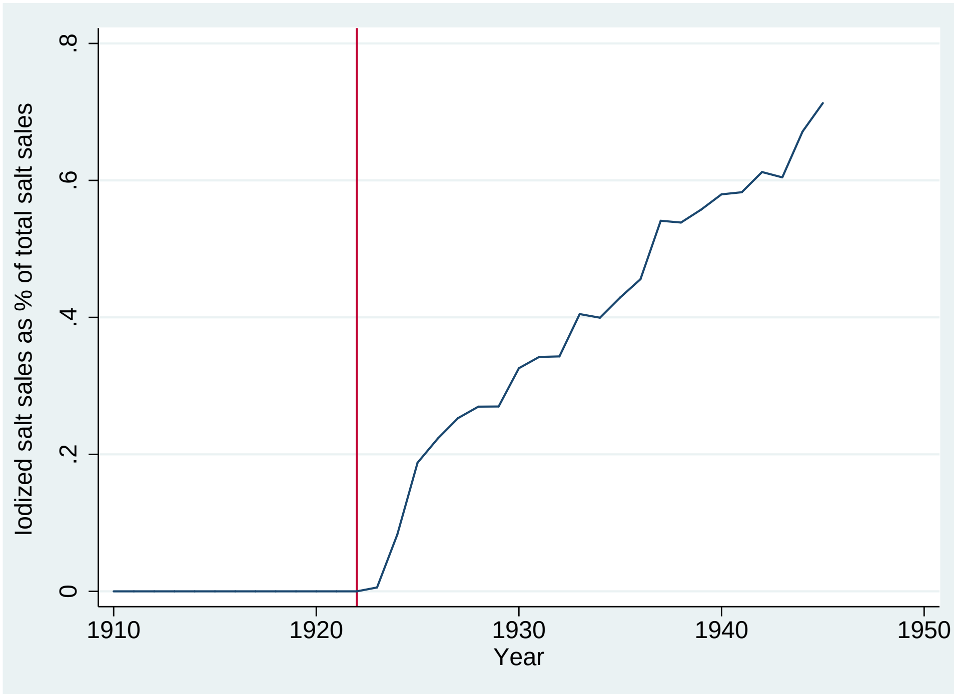
It was in November 1922 that United Swiss Rhine Salt Works (USRSW)[14] started adding iodine to salt (5 mg. KI or 3.75 mg. I per kg salt) and selling the new product at the same price as non-iodized salt. Even before that date, though, iodine prophylaxis had become popular, especially since Marine and 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 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, iodized salt became popular fast.

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-

[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.

Figure 1: Iodized salt penetration in Switzerland



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

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). 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 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).

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: 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					
	Born before 1922	Born after 1922	Born before jump in iodized salt sales	Born after jump in iodized salt sales	Total
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					
	Born before 1922	Born after 1922	Born before jump in iodized salt sales	Born after jump in iodized salt sales	Total
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 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%

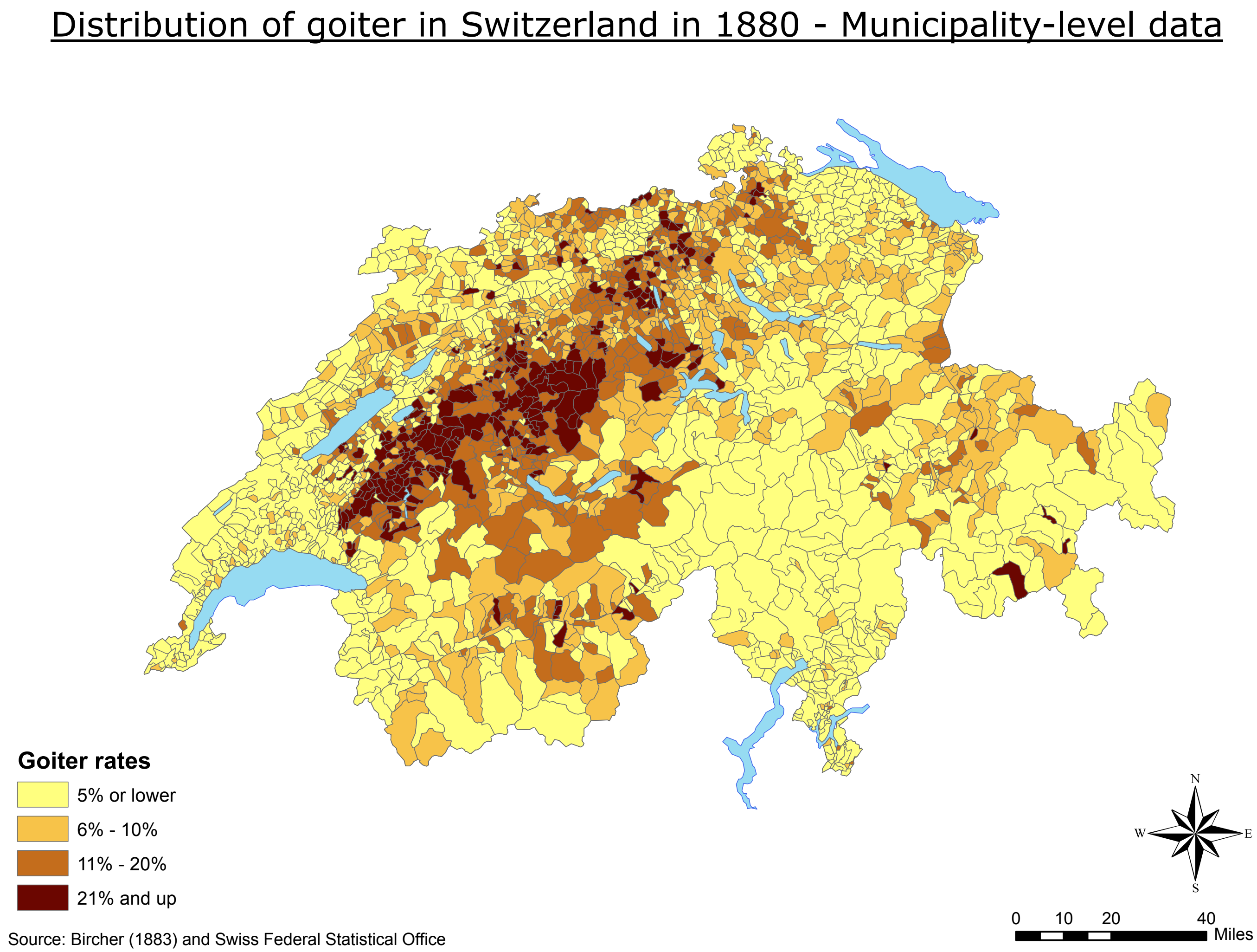
Notes: High-goiter regions are defined as those districts belonging to the top 25% of the population-weighted goiter distribution

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 and 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 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.

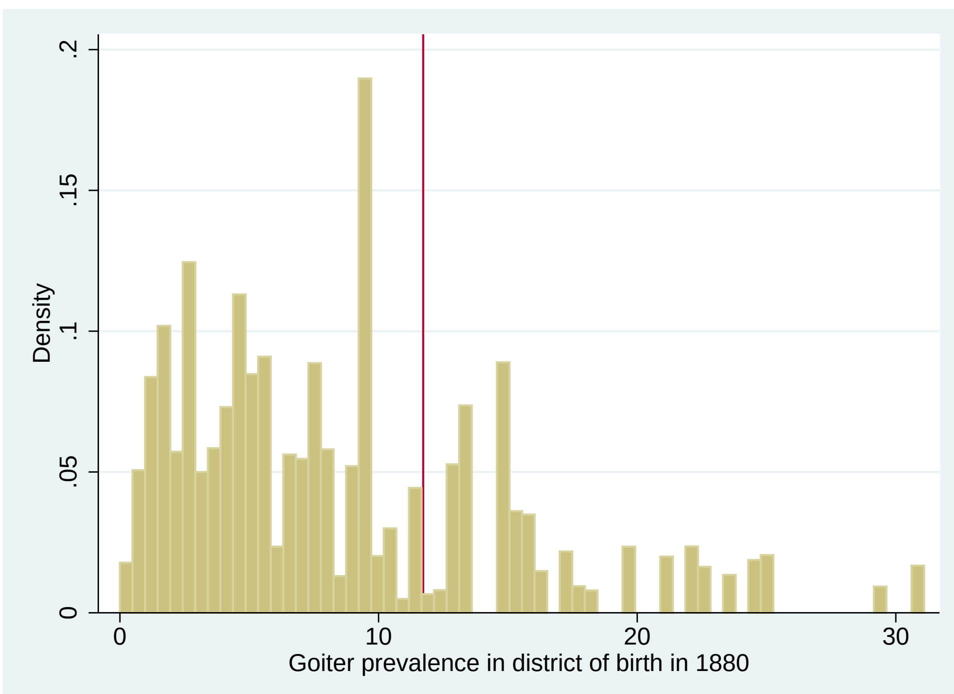
Because many municipalities have been divided or merged with others since Bircher's time, I construct new measures of underlying goiter prevalence in the population at the district level (one administrative level up from the municipality level), using the same method used by Bircher (Bircher 1883)[18]. Figure 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.

[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.

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 4 and Section 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 3: Histogram of goiter prevalence in Switzerland



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

Figure 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 3 marks the 75th percentile cutoff 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.

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.

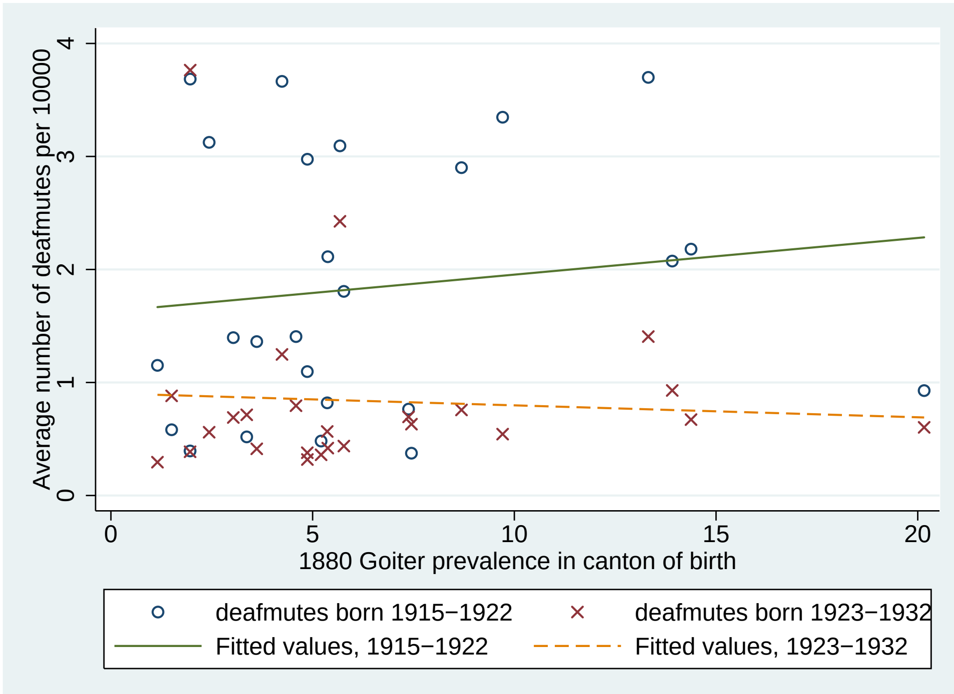
Figure 4 combines Wespi's data on deaf-mutism and Bircher's data on goiter prevalence in 1883 (aggregated at the canton level) in a scatterplot. I divide Wespi's data in two categories: cohorts born in 1915-1922 (before iodization), and cohorts born in 1923-1932 (after iodization). Each observation is a canton-time period combination, so that there are two observations for every 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 5 is a plot of the prevalence of deaf-mutism in each cohort born in 1915-1932,

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

[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 4: Deaf-mutism and 1883 Goiter Prevalence before and after iodization



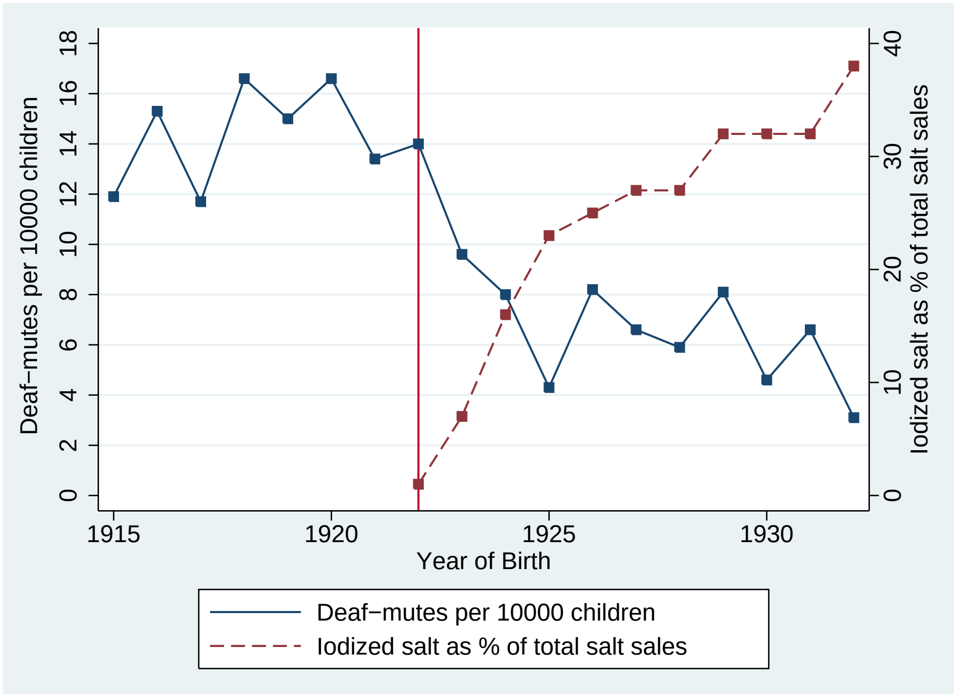
source: *Bircher (1883), Wespi (1945), and 1970 Swiss Census*

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.

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. Rates of deaf-mutism fell rapidly after 1922

Figure 5: Deaf-mutism and Iodized Salt penetration



source: *reproduced from Wespi (1945)*

(Figure 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 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.

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

Figures 6 and 7 are regression-adjusted graphs, which show how the probability of graduating from secondary (Figure 6) and tertiary (Figure 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 8 and 9 show the regression-adjusted difference in coefficients between high- and non-high-goiter districts for secondary (Figure 8) and tertiary education (Figure 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 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 educa-

Table 3: Salt sales and education: Coefficient on high-goiter dummy X Born after 1922 dummy

	All cohorts	Born 1910-1935
WHOLE SAMPLE		
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.

tion. The coefficient of interest is β. 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 β 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 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 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 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 8.

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

8.1 A closer look into cantonal iodized salt sales

As manifested by the decrease in deaf-mutism rates described in section 6, the campaign for iodization had strong and immediate effects on the population. The graphs and regression results in section 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.

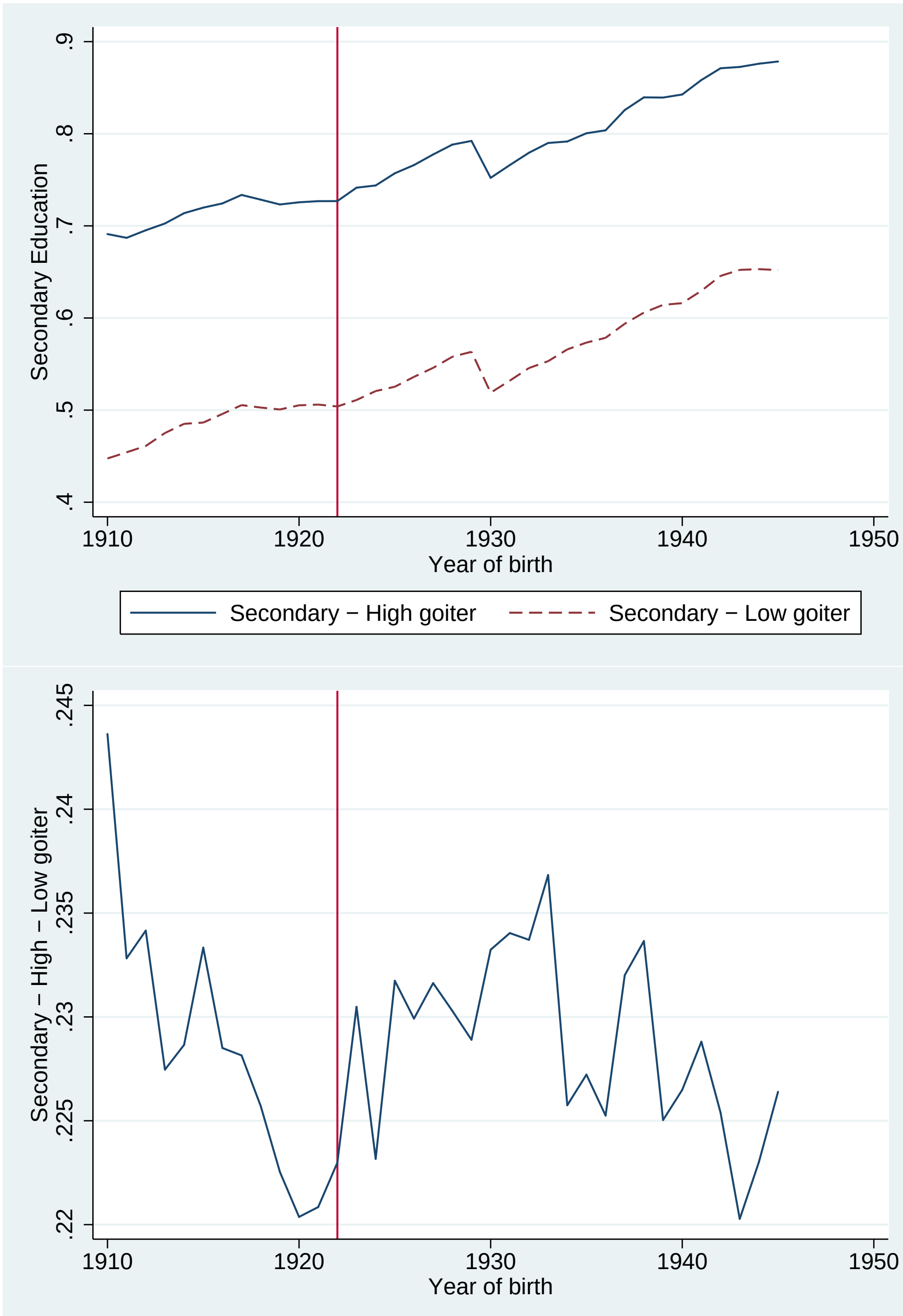
However, a closer look into the data paints a more complex picture. It seems that high-goiter cantons introduced iodized salt later than the rest of the country. Table 1A-1 in the Appendix contains annual, canton-level data of iodized salt sales as a percentage of total salt sales for the period 1922-1949[22]. 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

[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 6: Secondary education, difference between high-and low goiter districts



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

Figure 7: Tertiary education, difference between high-and low goiter districts

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

Figure 8: Secondary education, males and females, difference between high-and low goiter districts

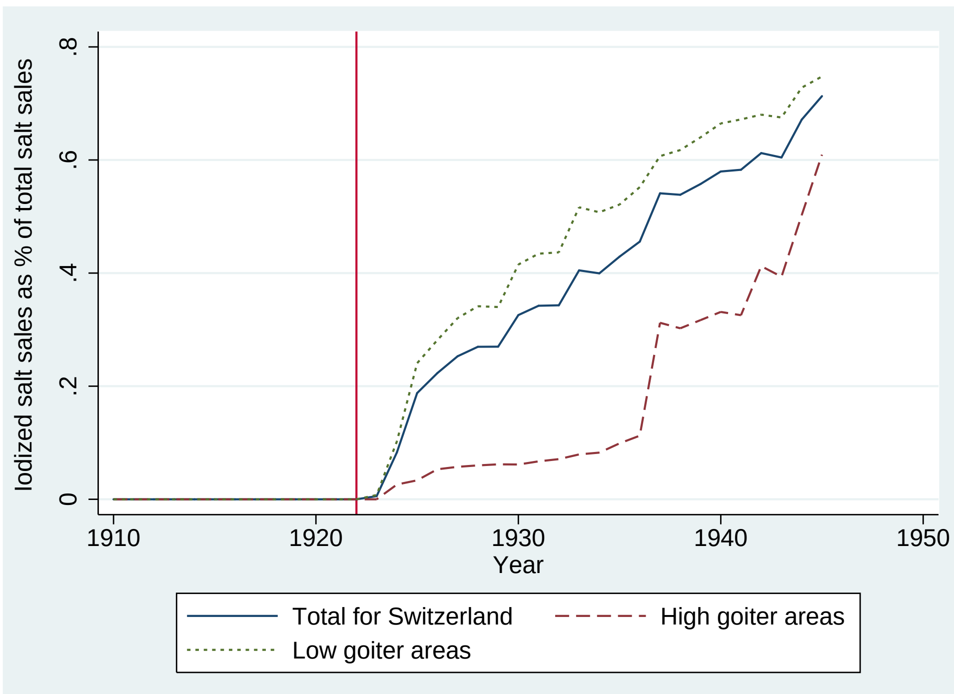
source: *Bircher (1883) and 1970 Swiss Census*

Figure 9: Tertiary education, males and females, difference between high-and low goiter districts

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

more 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 shows that the adoption of the "new salt" for country as a whole was gradual.

Figure 10: Iodized salt penetration in high- and low-goiter districts



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

Figure 10 confirms that high-goiter districts belonged to a large extent to cantons which iodized relatively late. Figure 10 is similar to Figure 1 in that it shows population-weighted averages of iodized salt sales, but apart from showing the countrywide average, Figure 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 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 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 7 and 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.

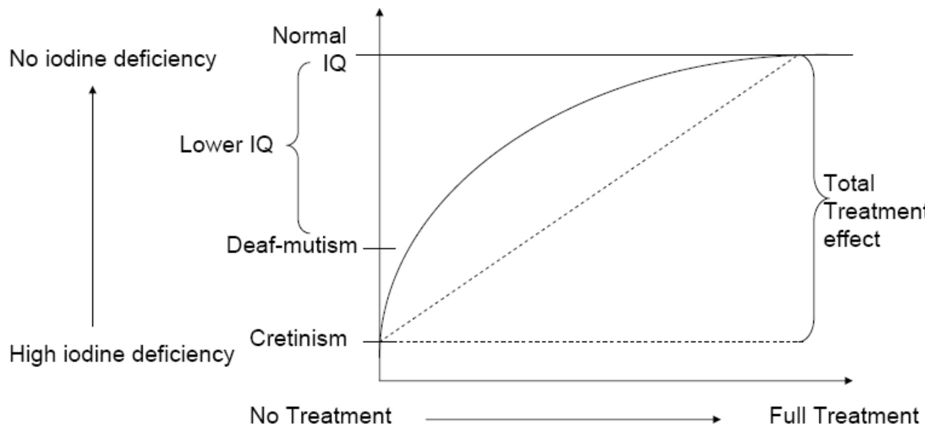
8.2 An iodine response function

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 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 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-

Figure 11: Iodine response function



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].

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

[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.

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 $outcome_{idy}$ 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 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 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.

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

Table 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.

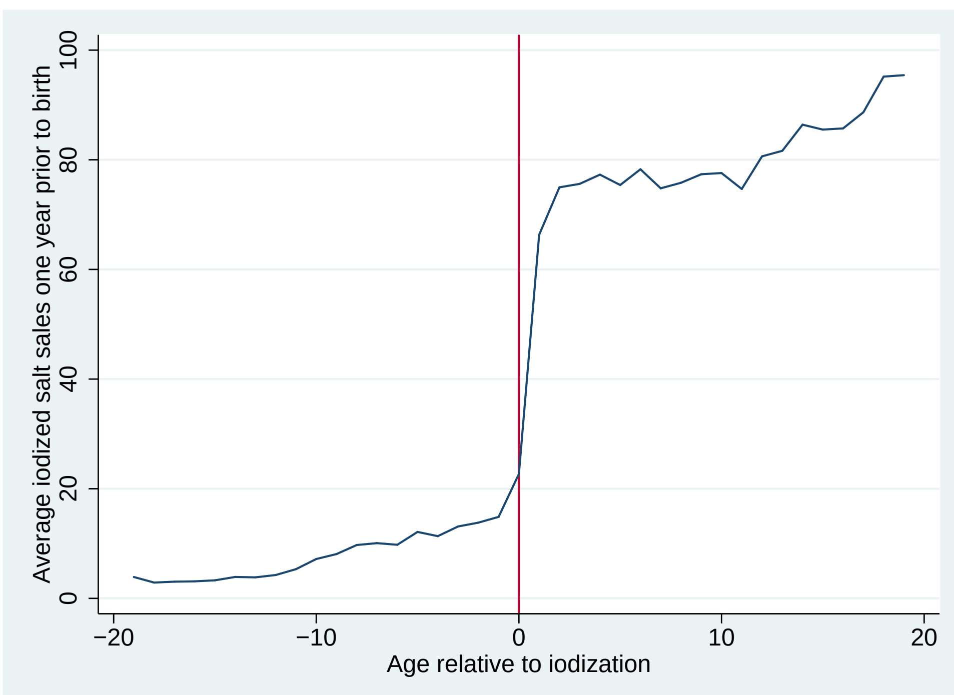
All regressions include canton of birth and cohort fixed effects, as well as a canton-specific trend.

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

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 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%.

Figure 12: Iodized salt sales by age relative to iodization



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

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 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 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 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 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

Table 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.

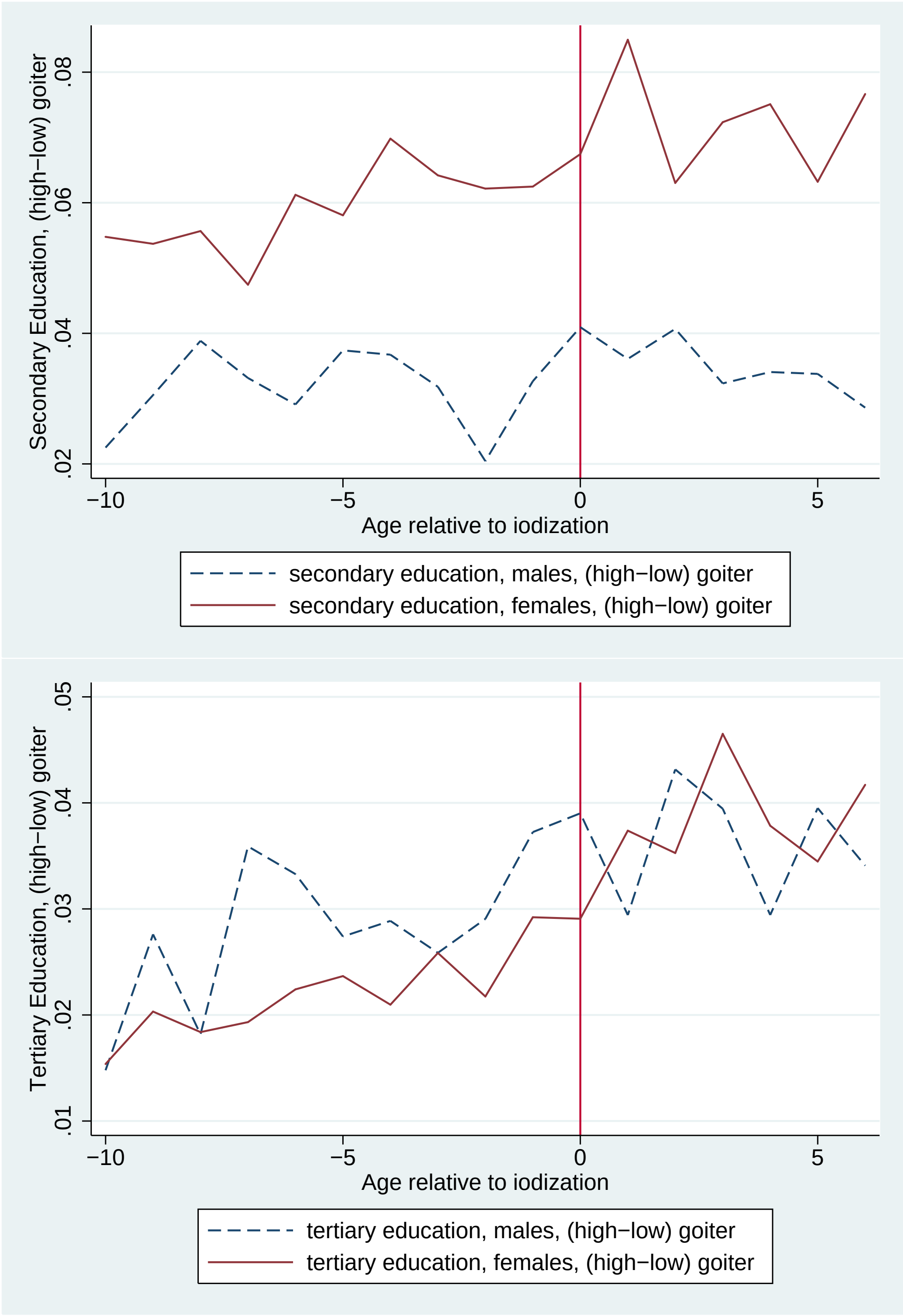
Columns (1) and (3) assume common cohort fixed effects for high- and non-high-goiter districts.

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 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*

(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, preliminary results of Table 3.

Figure 13 is a graphical representation of the results shown in Table 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:

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

$+ \textit{Trend before jump in iodized salt sales}$

$+$ *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 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 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

Table 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.

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.

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 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

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

more than the initial improvement in cognitive ability.

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

[26] Personal communication to the author.

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.

12 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)

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