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Cognitive Consequences of Iodine Deficiency in Adolescence: Evidence from Salt Iodization in Denmark

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Abstract

Over the past three decades, many countries have introduced iodized salt policies to eradicate iodine deficiency. While it is well known that iodine deficiency in utero is detrimental to cognitive ability, little is known about the consequences of iodine deficiencies after birth. This paper examines the impact of iodine deficiency in adolescence on cognitive performance. I identify the causal effect of iodine deficiency quasi-experimentally using the introduction of iodized salt in Denmark. Denmark went from a ban on iodized salt before 1998 to a mandate after 2001, making it an ideal national experiment. Combining administrative records on high school grades over a thirty-year period with geographic variation in initial iodine deficiency, I find that salt iodization increases the Grade Point Averages of high school students by 6-9 percent of a standard deviation. This improvement is comparable to the benefits of more standard school achievement policies and at much lower costs.

JEL Codes: I15, I18, J24

Key words: Iodine Deficiency, Iodized Salt, Nutrition, Human Capital, Health

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1 Introduction

More than two billion individuals lack essential vitamins and minerals (WHO et al., 2007), and these micronutrient deficiencies are major causes of disease globally. Over the past three decades, the WHO has initiated global efforts to increase food fortification, which has reduced the incidence of micronutrient deficiencies (Allen et al., 2006). The adoption of iodized salt to eradicate iodine deficiency is a leading example of such food fortification. Iodine is a crucial mineral for metabolic functioning and brain development. While iodized salt has been used since the 1920s in the US and Switzerland to prevent goiter, it became a global health policy after the 1980s, as researchers established that iodine deficiency during pregnancy is detrimental to brain development in children. In 1993, the WHO recommended worldwide adoption of iodized salt, and from 1990 to 2007 a large number of countries introduced salt iodization policies, thereby increasing worldwide access to iodized salt from 20 to 70 percent (WHO et al., 2007).

Today, iodine deficiency is recognized as the leading cause of preventable mental retardation and recent studies in economics have shown that the introduction of iodized salt in the US and Switzerland increased the average IQ, educational attainment and adult earnings of individuals exposed to iodized salt while in utero (Politi, 2010, 2015; Feyrer et al., 2017; Adhvaryu et al., 2019).

However, while salt iodization affects the entire population, little is known about the cognitive effects on individuals exposed after birth. A small experimental literature finds that iodine supplementation improves cognitive performance among school-age children (Zimmermann et al., 2006; Gordon et al., 2009), but it is unknown whether the benefits found in these small-scale controlled experiments also apply to real-world food fortification, and, in particular, to the recent wave of salt iodization policies implemented around the world.

This paper studies the postnatal effects of salt iodization policy on cognitive performance. Specifically, I estimate the effect of the introduction of iodized salt in Denmark during the period 1998-2001 on the Grade Point Average (GPA) of high school students.

The Danish fortification policy provides unique conditions to study the effect of the recent wave of salt iodization policies. First, the policy was implemented within a few years and legislation changed from a ban on iodized salt before 1998 to mandated iodization of salt after 2001. This sharp policy change resulted in a large and immediate improvement in the iodine status of the population, providing an ideal experiment to study the effect of salt iodization.

Secondly, the degree of iodine deficiency in Denmark varies substantially across areas due to differences in the concentration of iodine in drinking water. Drinking water accounts for 25 percent of the iodine intake in Denmark and the concentration of iodine in water varies more than 100-fold across areas (Pedersen et al., 1999). As salt iodization should only matter in deficient populations, I use this natural source of variation in iodine intake as a measure of treatment intensity in a Difference-in-Differences design. Hence, I compare the impact of the introduction of iodized salt across individuals living in areas with high and low concentrations of iodine in drinking water.

Lastly, the availability of high-quality administrative data over three decades makes it possible to credibly estimate treatment effects. I measure cognitive performance in adolescence using the final grade point average of high school students. The data covers all students graduating from 1981 to 2011, providing 18 pre-reform years to verify the common trend assumption of the Difference-in-Differences method and 10 post-reform years to study the benefits of salt iodization. I combine the administrative records with information on the iodine concentration in local drinking water, based on data from ground water samples collected by the Geological Survey of Denmark and Greenland (GEUS).[1][2]

My main finding is that salt iodization increases the final GPA of high school students by 0.06-0.09 standard deviations. The effect is immediate, with grades increasing from the first year of implementation, suggesting that salt iodization produces a contemporaneous improvement in cognitive performance among adolescents. To my knowledge, this is the first evidence that the benefits of salt iodization are not limited to the in utero period.

The estimated benefits of salt iodization are of the same order of magnitude as recent estimates of the effect of improved school lunch quality on students' test scores in US public schools (Anderson et al., 2018). Compared to more standard school achievement policies, the effect of salt iodization amounts to one-third to one-fourth of the benefit of reducing class sizes (Krueger, 2003). However, because salt iodization is very cheap, it is 20,000 times more cost-effective than reducing class sizes.[3] This suggests that even in developed countries, improving students' nutrition is a low-hanging fruit.

There is substantial heterogeneity in the response to salt iodization. First, the benefits are largest for low-achieving students. The effect of salt iodization on the bottom quartile of grades is three times larger than on the top quartile of grades. This suggests that policies designed to correct nutritional deficiencies can reduce inequality in school performance and productivity

[1] GEUS is a research and advisory institution in the Danish Ministry of Energy, Utilities and Climate. Among other things, it collects and makes publicly available, all water sample analyses used in the monitoring of drinking water quality. Additional information may be found at https://eng.geus.dk/about/.

[2] All drinking water in Denmark is derived from ground water reserves.

[3] According to estimates by the 2008 Copenhagen Consensus (Horton et al., 2008) the cost of salt iodization is 0.05 USD/person/year. Estimates of the costs and benefits of reducing class sizes comes from Krueger (2003). He estimates the cost of reducing class sizes from 22 to 15 students to be USD 3,385/student/year (1998 Dollars), see table 5, row 1 in Krueger (2003). The benefit from reducing class size is an increase in test scores of 0.2 standard deviations (Krueger, 2003).

(Deaton, 2003). Second, I find suggestive evidence that salt iodization benefits women more than men. This is consistent with previous findings in the literature on in utero exposure to salt iodization and with the medical literature showing higher prevalence of iodine-deficiency-induced disorders among women (Pedersen et al., 2002; Vanderpump, 2011). Lastly, I show that the benefits of salt iodization are larger for students who are more iodine-deficient. The Danish population was mildly to moderately deficient before the introduction of iodized salt. I show that the treatment effect is exponentially larger for students living in more iodine-deficient areas and that mild deficiency does not affect cognitive performance. This hints at a very concave relationship between cognitive performance and iodine intake, in which the largest benefits of salt iodization are only observed in severely deficient countries.

I study a recent salt iodization policy in a wealthy country in Europe. Although iodine deficiency is not considered to be a public health concern in many European countries, Europe has the lowest rate of salt iodization of any WHO region (WHO 2007b) and 44 percent of school-age children in Europe do not consume adequate amounts of iodine (Andersson et al., 2012). Hence, my results suggest that even though severe iodine deficiency is rare in Europe, the benefits of increasing accesss to iodized salt are non-negligible.

To assess the postnatal benefits of salt iodization in more deficient countries, I estimate the relationship between initial iodine deficiency and the benefits of iodized salt and use this to extrapolate beyond the range of deficiency observed in Denmark. I predict an average treatment effect of 0.13 standard deviations for students with a moderate deficiency and 0.5 standard deviations for students with a severe deficiency. Globally, 8.1 percent of school-age children are moderately iodine deficient, while 5.2 percent are severely iodine deficient (Andersson et al., 2012). Hence, the postnatal benefits of salt iodization are potentially much larger in other countries.

My results confirm that the benefits of iodine supplementation to children found in experimental studies also apply to real-world fortification policies (Zimmermann et al., 2006; Gordon et al., 2009). However, the biological mechanism behind this result is unclear. Iodine deficiency may affect cognitive performance in adolescence in two ways: (*i*) by impairing normal metabolic functioning, causing fatigue and reduced brain activity and (*ii*) by disturbing normal brain development during childhood and adolescence, causing permanent brain damage (Gordon et al., 2009). If salt iodization affects grades by preventing brain damage, the benefits should accumulate over time, resulting in larger treatment effects for students first exposed to iodized salt in early childhood. If salt iodization affects grades through the metabolism, only current iodine intake should matter and treatment effects should be identical for students first exposed to iodized salt in early and in late childhood. Empirically, I find similar treatment effects for students first exposed to salt iodization at ages 9 to 18, i.e. between ten and one years before finishing high school. This suggests that in adolescence, iodine deficiency affects cognition through its effect on the metabolism rather than through brain damage. Since iodine deficiency affects the metabolism at all ages, this suggests that similar benefits may be found for adults. Considering that 29 percent of the world population and 30 percent of all school-age children remain mild to severely iodine deficient (Andersson et al., 2012), my results imply that there is still a large untapped economic potential in scaling-up salt iodization.

The rest of the paper is structured as follows: Section 2 provides more background on the biology of iodine deficiency and outlines the Danish salt iodization policy. Section 3 describes the data. Section 4 explains the empirical method. Section 5 presents the main results. Section 6 evaluates the robustness and external validity of the estimates. Section 7 concludes.

2 Iodine Deficiency and Iodized Salt in Denmark

The adverse effects of iodine deficiency originate from disturbances to the production of thyroid hormones in the thyroid gland. Thyroid hormones regulate the metabolism of most cells of the body and a lack or excess of these is associated a wide range of physical and psychological illnesses. When iodine intake is low, the body initiates a number of compensatory biological processes. The most important is thyroid enlargement, also known as goiter, which enables the thyroid gland to produce more thyroid hormones from a given input of iodine. While this compensation is effective when individuals are mildly iodine deficient, more severe cases result in insufficient thyroid hormone levels and a condition called hypothyroidism.

It is through hypothyroidism that iodine deficiency affects cognitive performance. With too low thyroid hormone levels the metabolism slows down. The symptoms include lethargy, weight gain, and impaired brain activity (Samuels, 2014). This is the first of two mechanisms through which iodine deficiency can affect cognition. Thyroid hormones also control a wide range of processes responsible for the development of the brain and organs. During critical periods of brain development this can cause irreversible brain damage and long-term consequences for cognitive ability (Delange, 2001; Delange and Hetzel, 2004). This second mechanism is especially important during the prenatal period, when brain development is most rapid (Gilmore et al., 2018). However, brain development continues throughout childhood and adolescence. Therefore, both of these mechanisms could be important when considering the effect of salt iodization on cognitive performance in adolescence.

Excessive iodine consumption of up to 10 times the recommended intake is considered safe (Rasmussen et al., 1996). However, sustained overactivity of the thyroid gland due to inadequate iodine intake can cause the regulation of the system to break down (Laurberg et al., 2009). If iodine intake is then increased subsequently, the thyroid gland cannot return to normal activity. Hence, correcting iodine deficiency can lead to an excess of thyroid hormones and a condition called hyperthyroidism. In contrast to hypothyroidism, hyperthyroidism is a state of overactive metabolism, causing nervousness, weight loss and sweating. Together with goiter, hypothyroidism and hyperthyroidism are the most common of iodine deficiency disorders.

Danish Salt Fortification

Salt iodization has been used to prevent high rates of goiter in the US and Switzerland since the 1920s. In Denmark, iodine deficiency was not considered a problem during most of the 20th century (Laurberg et al., 2009).[4] Several large studies of thousands of school-age children in Denmark found up to 15 percent goiter rates in some groups of the population, but no indication of clinically relevant goiter on a national level. Therefore, the Danish National Food Agency did not allow salt producers to add iodine to salt. In the 1980s and 1990s evidence of iodine deficiency among older individuals and pregnant women started to accumulate, and in 1994 the Danish National Food Agency created a working group to determine whether an iodization program was needed. In 1996 the working group concluded that the population was mildly-to-moderately iodine deficient and that an iodized salt program should be implemented. In June 1998, the National Food Agency abolished the existing ban on salt fortification and introduced a voluntary salt iodization program in collaboration with salt producers. The program was expected to increase the average daily iodine intake by 50 μg, from 50-100 μg/day (Rasmussen et al., 2002) to somewhere within the recommended range of 100-150 μg/day.

The voluntary program proved unsuccessful, with an average increase in iodine intake below 10 μg/day (Laurberg et al., 2009). Two years after implementation, only 50 percent of household salt and close to no salt in the food industry was iodized. As a response, the National Food Agency decided to make the policy mandatory. This second reform was gradually implemented between July 2000 and April 2001, during which the remaining stocks of non-iodized salt could still be sold. According to estimates by Rasmussen et al. (2007), the two reforms combined met the goal of a 50 μg/day increase in average iodine intake. Both reforms were announced to the public and the issue received considerable media coverage in regional and national newspapers.

[4]This section is, to a large extent, based on a review article by Laurberg et al. (2009), which describes the historical context of the Danish fortification policy and the research of the DanThyr project - a research group set up to monitor the health effects of salt fortification in Denmark.

The health effects of the Danish salt fortification policy have been studied extensively. Using identification strategies similar to the one applied in this paper, medical researchers have confirmed that the increase in iodine intake following salt fortification led to a significant improvement in health, with a reduction in the incidence of thyroid enlargement and goiter (Krejbjerg et al., 2014). Medical researchers have also documented a temporary increase in the incidence of hyperthyroidism (Pedersen et al., 2006), which is expected when iodine intake is suddenly increased after prolonged exposure to iodine deficiency. This suggests that the population was in fact iodine deficient prior to the reforms, and that the iodization policy was effective in eradicating iodine deficiency.

3 Data

The empirical analysis is based on high quality Danish administrative data on school achievement. High school grades have been recorded since 1977, while the records for lower/middle secondary school grades only go back to 1999.[5] For this reason, I focus on high school students and their individual grade point averages as the main outcome of interest.

High school is voluntary in Denmark and students interested in upper secondary education can choose between four different programs that lead to the following final exams; (1) a standard Academic High School Examination (STX), (2) a Higher Technical Examination (HTX) focusing on science and technology, (3) a business-oriented Higher Commercial Examination (HHX), and (4) a Higher Preparatory Examination Course (HF) meant for adults interested in further education. STX, HTX and HHX are all three-year programs while HF is a two-year program.

Grades of HHX and HTX students are only recorded from 1999 and are therefore not included in the analysis. As I consider the effect of iodine deficiency in adolescence and the HF program is intended for adults, HF students are also excluded. Hence, in the main analyses, I focus exclusively on STX students.

The STX program most closely resembles high school education in other countries and, over the data period, 60-70 percent of all high school students in Denmark were enrolled in the STX program. However, the main difference between the programs is the elective course catalog, and students can apply to all tertiary institutions, regardless of which high school program they graduate from. In the appendix, I show that the main results are not sensitive to including HF students in the analysis.

[5] In Denmark, school attendance is compulsory until the end of year 9. Children attend primary school ('Folkeskole') from kindergarten to year 9, which encompasses primary and lower/middle secondary education. High school refers to years 10 to 12.

Courses are categorized by A, B and C levels according to difficulty and duration. A-level courses are the most comprehensive and classes last from the first year of high school to graduation. C-level and B-level courses are predominantly one- and two-year courses, respectively. Grades take two forms; class participation grades and exam grades. The majority of exams take place just before graduation, and 60 percent of grades are determined during the last year of school. After graduation, the GPA determines which universities and tertiary courses students are eligible for acceptance into, and there is considerable incentive to perform well.

Beyond educational outcomes, the data set includes a wide range of socioeconomic characteristics of the students and their parents. The administrative data covers the universe of Danish citizens dating back to 1980. Parental characteristics include income, wealth, education, age, labor market participation, and marital status. For continuous variables, I take the average of the father and mother's registered values in the year the child graduates from high school. For labor market participation, I define dummies equal to one if at least one parent belongs to a certain category, e.g. employed, unemployed, retired.[6] Student characterics include age, number of siblings, gender, school institution, and municipality of residence. Lastly, I use data from health registers which contain information on the birth weight and birth length of all children born after 1973.

A new high school reform was implemented in 2005. Among other things, the reform introduced a new grading scale, a different course structure, and additional requirements for cross-disciplinary activities. The first cohort of students affected by these changes graduated in 2008. Because of this, and a large-scale municipality reform in 2007, the main figures present estimates using only the period 1981-2006.[7] I show the results for the extended period, 1981-2011, when studying the long-run consequences of salt iodization.

The final sample consists of 524,932 STX students graduating during the years 1981-2011.

4 Empirical Method

I use a Difference-in-Differences strategy to identify the causal effect of salt iodization on cognitive performance in adolescence. This approach requires time-series variation in iodine intake and cross-sectional variation in treatment intensity. The time-series variation comes from the introduction of iodized salt in Denmark between 1998 and 2001. As a source of variation in treatment intensity, I exploit pre-existing differences in iodine deficiency across areas of Den-

[6]Labor market participation variables are measured in November. High school students graduate in June. Therefore, the year prior to graduation is used for these variables.

[7]The year 1980 is left out because labor market variables are not available in that year.

mark. Since salt iodization should only matter for deficient students, I compare the effect of the introduction of iodized salt in Denmark across iodine-deficient and iodine-sufficient areas.

I use geographical variation in the concentration of iodine in local drinking water as a measure of pre-existing iodine deficiency. All tap water in Denmark is derived from ground water reserves (Voutchkova et al., 2015), and the amount of iodine in ground water is determined by local geological conditions. Before the introduction of iodized salt, tap water accounted for 25 percent of the total iodine intake in Denmark (Rasmussen et al., 2000) and drinking water was one of the main drivers of regional differences in iodine deficiency (Rasmussen et al., 1996).[8] Local geological conditions also affect the iodine concentration in milk, which accounts for another 25 percent of the total iodine intake (Rasmussen et al., 1996). In combination, these correlations produce a clear positive relationship between iodine in drinking water and iodine in urine - the most common measure of iodine intake (Pedersen et al., 1999).[9]

I measure the iodine concentration in drinking water using data from the Geological Survey of Denmark and Greenland (GEUS), which features 2,800 unique samples of ground water from all parts of Denmark. To relate these measurements to the iodine intake of high school students, I collapse the data at the municipality level.[10]

Figure 1 displays the iodine concentration in drinking water across municipalities in Denmark. The iodine concentration ranges from 1 $\mu g/liter$ to 67 $\mu g/liter$. Hence, with an average tap water consumption of 1.7 $liter/day$, drinking water accounts for 1 to 76 percent of the recommended iodine intake of 150 $\mu g/day$.[11] The lowest concentrations are found in Mid-West Denmark and the highest concentrations are found in North-West Denmark and East Denmark. Hence, while inhabitants in Mid-West Denmark get almost no iodine from tap water, inhabitants in North-West Denmark and parts of East Denmark get up to 76% of the recommended iodine intake from tap water.

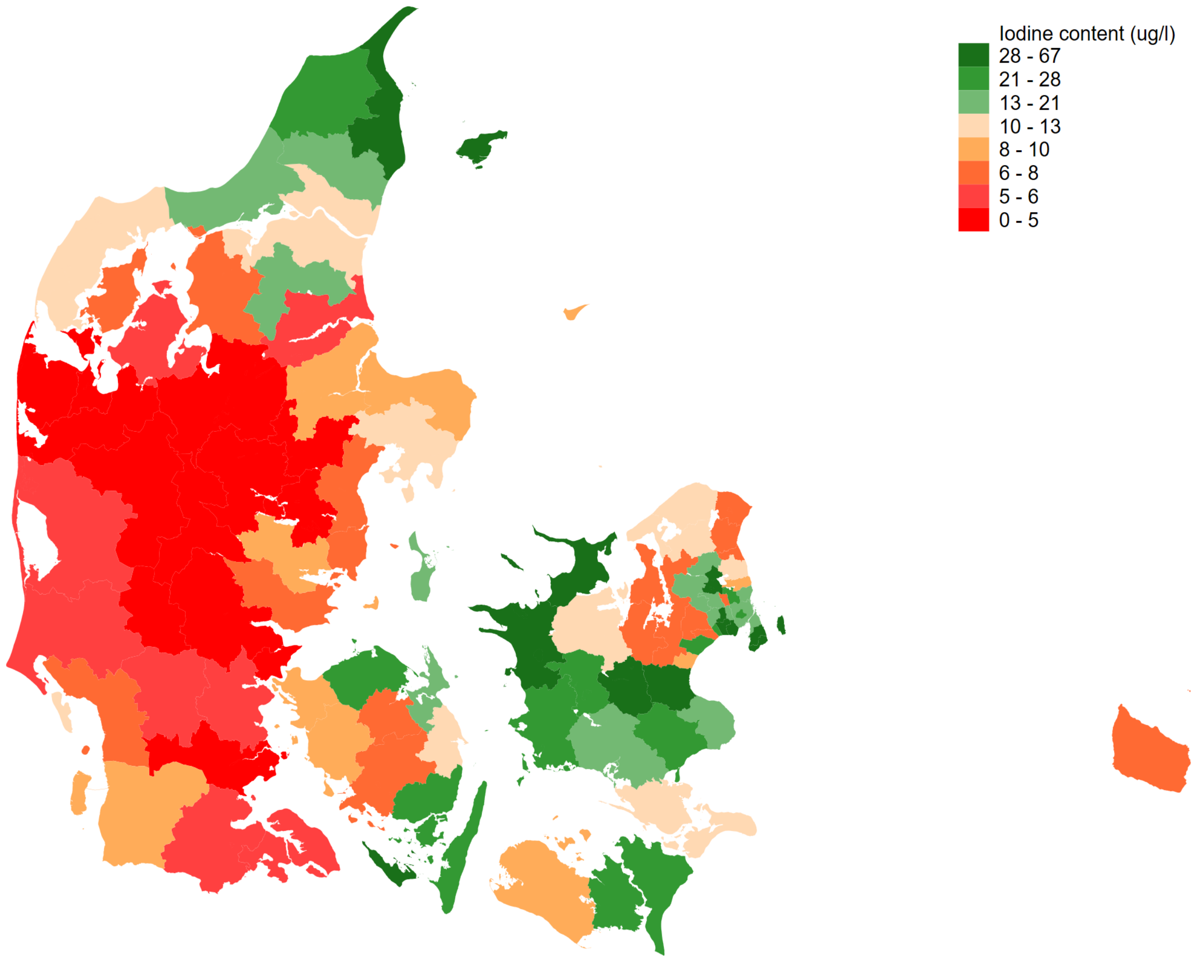
[8] Bottled water consumption is very low in Denmark (Voutchkova et al., 2015).

[9] Other studies have used geographical variation in goiter incidence rather than iodine in drinking water as a measure of iodine deficiency, see Feyrer et al. (2017); Politi (2015, 2010). While goiter is a more direct measure of thyroid hormone deficiency, it is arguably a less exogenous one. Goiter is caused by low intake of milk and fish, and the use of goitrogens (goiter-inducers) such as alcohol and cigarettes. The consumption of each of these is correlated with socioeconomic status. In contrast, the iodine concentration in drinking water is solely determined by local geological conditions. Therefore, using iodine concentrations in drinking water rather than goiter incidence rates provides a more exogenous source of variation in iodine deficiency. Nonetheless, because drinking water is an important determinant of iodine intake, the two measures are highly correlated, see Feyrer et al. (2017).

[10] In 2007 a big municipal reform reduced the number of municipalities in Denmark from 272 to 98. To avoid this data break, I use post-2007 municipality borders throughout the analysis.

[11] This number comes from (Pedersen et al., 1999), who regress iodine in urine – a common measure of iodine intake – on the iodine concentration in tap water and find a well-fitted linear relationship of $IodineUrine = 43.2 + 1.7 * IodineWater$, where $IodineWater$ is measured in μg/liter and $IodineUrine$ is measured as μg/day. This is consistent with an average tap water consumption of 1.7 liters/day, which is reasonable since bottled water consumption is very low in Denmark (Voutchkova et al., 2015).

Figure 1: Iodine Concentration in Ground Water in Danish Municipalities



Note: The figure shows the iodine concentration (μg/liter) in ground water for each municipality in Denmark. Recommended iodine intake is 150 μg/day. The values are based on data from ground water analyses by the Geological Survey of Denmark and Greenland (GEUS).

I define two treatment variables based on the drinking water data. (1) A discrete treatment variable equal to one for students living in municipalities with below median iodine concentrations in drinking water. (2) A continuous measure of treatment intensity specified as the inverse of the iodine concentration in local drinking water, $Treat = \frac{1}{IodineContent}$.

I normalize the continuous treatment variable to reflect the difference in the response to salt iodization between an individual in the 5th and 95th percentile of the iodine concentration distribution.[12] As students in the 95th percentile are assumed to be iodine-sufficient, this represents the treatment effect on students with the 5 percent lowest iodine concentrations in drinking water.

[12] I normalize by dividing the variable by the difference in iodine concentration between the 95th and 5th percentile of the iodine concentration distribution. In this way, an increase in the continuous variable of one reflects the effect of increasing the iodine concentration from the 5th percentile to the 95th percentile.

I estimate the effect of salt iodization using a standard Difference-in-Differences model. As high school students in Denmark graduate in late June and the two salt iodization reforms were implemented in June 1998 and between July 2000 and April 2001, the reforms were implemented too late in the year to affect the GPA of students who graduated in 1998 and 2000/2001. Therefore, the first students to benefit from the voluntary program in 1998 and the mandatory program in 2000-2001 graduated in 1999 and 2001/2002, respectively. The estimation model is as follows:

$$GPA_{it} = \beta_0 + \sum_{t=t_0+1}^{T} \beta_{1t} I(year = t) + \beta_2 Treat_i + \beta_3 P1_t \times Treat_i + \beta_4 P2_t \times Treat_i + \delta X + \epsilon_{it}, \quad (1)$$

Where GPA_{it} is the individual GPA of high school students, $I(year = t)$ are year dummies, $P1_t$ and $P2_t$ are dummies for post-reform years 1999-2001 and 2002-, $Treat_i$ is either the discrete or continuous treatment variable, X is a vector of controls and ϵ_{it} is an error term. Coefficients β_3 and β_4 reflect the treatment effect of the 1998 and 2000-2001 reforms, respectively.

The identifying assumption is that outcomes of treated and untreated students would have followed similar trends had it not been for the introduction of iodized salt. This common trend assumption is not directly testable, but its validity can be assessed by studying pre-trend differences. If the GPA of students in iodine-rich and iodine-poor municipalities follow similar trends prior to salt iodization, it is reasonable to assume that they would have continued to do so in absence of the reforms. Therefore, I also estimate regressions of the form:

$$GPA_{it} = \beta_0 + \sum_{t=t_0+1}^{T} \beta_{1t} I(year = t) + \sum_{t=t_0}^{T} \beta_{2t} I(year = t) \times Treat_i + \delta X + \epsilon_{it}, \quad (2)$$

Where the β_{2t} coefficients reflect the difference in the average GPA of students across iodine-poor and iodine-rich municipalities over time.

Even with identical pre-trends, the common trend assumption is violated if grades in iodine-poor municipalities increase relative to grades in iodine-rich municipalities for reasons unrelated to salt iodization, at the introduction of the reforms. In this setting, there are two types of shocks that can cause such a bias: (1) Contemporaneous shocks to determinants of grades and (2) endogenous selection into high school across years. I discuss each of these in the robustness section and argue that they do not pose a threat to the identification strategy.

Summary statistics

Table 1 presents summary statistics for the high school graduates in the data. The data is split into treatment and control groups using the discrete treatment variable (below median iodine concentration in drinking water). Overall, the characteristics of the students are remarkably well balanced across the two groups.

The average age of high school graduates in the treatment and control group is 19.43 and 19.39. More girls than boys graduate from the STX program, with only 40 percent boys in the treatment group and 41 percent in the control group. The students choose between two broad course packages; Science and Humanities. Science students follow courses in Mathematics, Physics, and Chemistry, while Humanities students take classes in Latin, French, German, and Spanish. Even this choice variable is balanced across groups with 62 percent of the students taking the Science program. The grade point averages of graduates – the outcome variable in the empirical analysis – range from 6 to 13, with an average of approximately 8.25 and a standard deviation close to one.[13]

Parental characteristics are also similar in the two groups. Parents in the treatment and control group are, on average, 49 years old and have around 13 years of schooling. However, parents in the treatment group have significantly less wealth and income than parents in the control group.

The bottom rows of table 1 show how population density in the municipality varies across the treatment and control group. The treatment group is more likely to live in a rural area than the control group, with 42 percent of the students in the treatment group living in thinly populated areas, compared to 27 percent of the students in the control group.[14]

To show that treatment status is not systematically correlated with characteristics of the students and their parents, I reestimate the difference in characteristics, controlling for whether the student lives in West or East Denmark. These coefficients are shown in column 4 of table 1. Once I control for the fact that most students in the treatment group live in West Denmark, see figure 1, the coefficients on parental characteristics are either insignificant or have the opposite sign to the raw differences in column 3. The same is true for the differences across rural and urban areas. Hence, even though treatment assignment is not random, it is not systematically related to characteristics of the students. In the robustness section, I show that the main results of the paper are robust to using only within-West/East Denmark variation in treatment.

[13]Before 2008, students were given the following grades: 0, 3, 5, 6, 7, 8, 9, 10, 11 and 13. 0 is the lowest possible grade and 13 is the highest. A grade of 6 or higher is a pass. In order to graduate high school, students need a grade point average of least 6.

[14]The geographical groups are based on Eurostat's DEGURBA (Degree of Urbanisation) classification http://ec.europa.eu/eurostat/ramon/miscellaneous/index.cfm?TargetUrl=DSP_DEGURBA

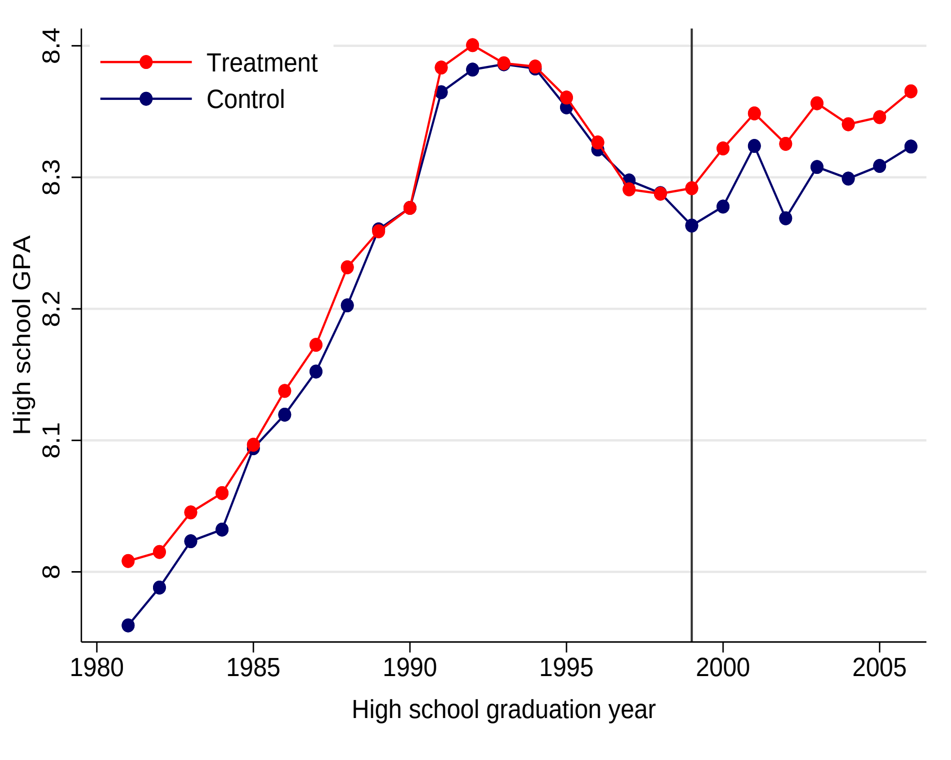
Table 1: Summary Statistics of STX Graduates from 1981 to 2006

	Treatment (1)	Control (2)	Difference (3)	Difference, Within Region (4)
Student Characteristics				
Age	19.43	19.39	0.05	-0.03
	(0.68)	(0.75)	(1.58)	(-0.90)
Male	0.40	0.41	-0.01	0.01
	(0.49)	(0.49)	(-2.41)	(1.02)
Number of Siblings	0.70	0.66	0.04	0.02
	(0.78)	(0.75)	(3.30)	(1.48)
Science Line[a]	0.62	0.62	-0.00	0.00
	(0.49)	(0.49)	(-0.55)	(0.66)
GPA	8.26	8.23	0.03	0.03
	(0.95)	(0.98)	(2.07)	(2.39)
Parental Characteristics				
Number of Parents	1.95	1.94	0.01	0.00
	(0.22)	(0.24)	(3.88)	(2.48)
Parental age	48.6	48.6	-0.04	-0.05
	(4.8)	(5.0)	(-0.56)	(-0.67)
Parental Years of Schooling	13.1	13.3	-0.17	0.09
	(2.7)	(2.6)	(-1.80)	(1.09)
Parental Wealth[b]	525,116	607,351	-82,235	14,352
	(4,671,869)	(4,048,689)	(-1.95)	(0.41)
Parental Income[b]	499,091	524,397	-25,306	12,165
	(559,997)	(560,580)	(-2.05)	(1.03)
Geographical Concentration[c]				
Densely Populated Area	0.20	0.34	-0.14	-0.03
	(0.40)	(0.47)	(-2.10)	(-0.52)
Intermediate Density Area	0.38	0.39	-0.01	0.02
	(0.49)	(0.49)	(-0.09)	(0.20)
Thinly Populated Area	0.42	0.27	0.15	0.02
	(0.49)	(0.44)	(2.09)	(0.20)
Number of Observations	208,622	215,259	423,881	423,881

Note: Columns 1 and 2 display the mean characteristics of the treatment and control groups, respectively. Standard deviations are reported in parentheses. Column 3 presents the difference between the treatment and control groups, based on a regression of the specific characteristic on the treatment dummy. *t*-statistics are reported in parentheses. Column 4 repeats this exercise, but controlling for a 'West Denmark'-dummy in the regression, such that coefficients reflect within-region differences between the treatment and the control groups. a) High school students choose between a Science or a Humanities course package. This variable is only recorded for the years 1981-2004. b) Wealth and income variables have been converted to 2011 levels using nominal GDP. c) The geographical categories follow from Eurostat's DEGURBA (Degree of Urbanization) classification.

5 Results

Figure 2: Trends in Grade Point Averages Before and After Salt Iodization

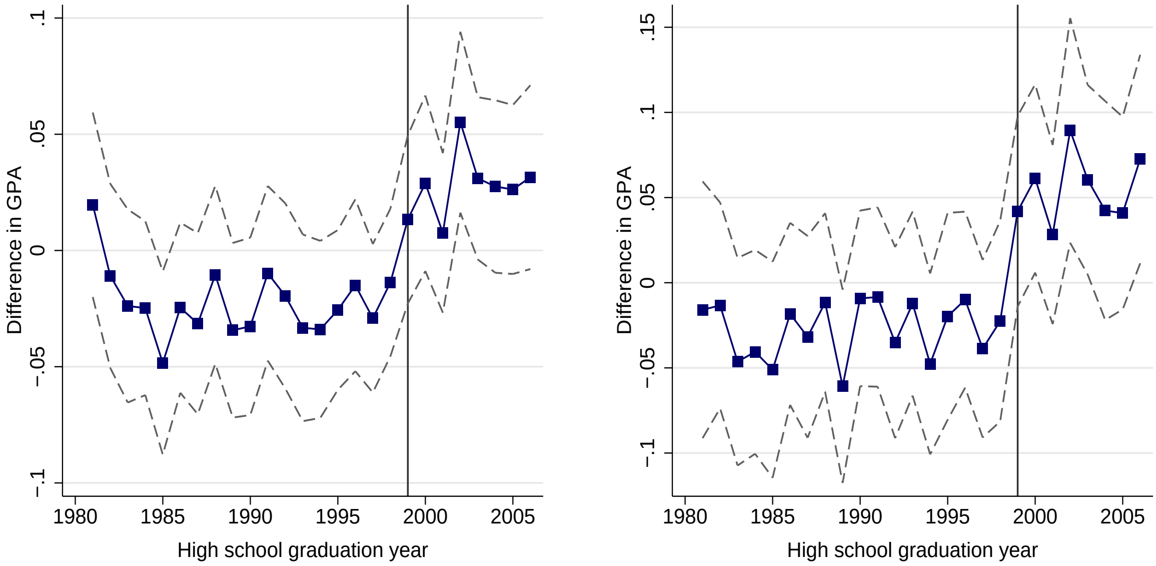


Note: The figure plots the average GPA among high school graduates in the treatment and control groups for each year during the period 1981-2006. The vertical line at year 1999 marks the introduction of iodized salt.

Figure 2 displays the average GPA of high school graduates in the treatment and control group for each year during the period 1981-2006. The average GPA is slightly higher in the treatment group than in the control group throughout the pre-reform period. If the students were randomly assigned to the treatment and control group, we would expect the opposite – that iodine deficiency is associated with lower grades. However, the Difference-in-Differences method does not require random assignment but only that the common trend assumption is satisfied. As shown in figure 2, grades in the treatment and control groups evolve in parallel throughout the entire 18-year pre-reform period. This suggests that the common trend assumption is valid and that grades in the two groups would have continued to mimic each other had it not been for the introduction of iodized salt.

Turning to the effects of salt iodization, it's clear from figure 2 that grades in the treatment group increase relative to the control group from 1999 and onward. This is consistent with the timing of the first salt iodization policy and the hypothesis that iodine deficiency impairs cognitive performance in adolescence.

Figure 3: Difference in Grade Point Averages Across Iodine-Deficient and Iodine-Sufficient Areas Over Time



A Discrete **B** Continuous

Note: The figure plots the difference in the average standardized GPA between iodine-deficient and iodine-sufficient areas for each year during the period 1981-2006. The dotted grey lines represent 95 percent confidence intervals using standard errors clustered by high school institution. Panel A shows the results for the discrete treatment variable, panel B shows the results for the continuous treatment variable. The baseline set of controls is used: Parents: Income percentile, years of schooling, age. Students: Age, birth year, gender, high school institution, number of siblings, birth order. The vertical line at year 1999 represents the introduction of iodized salt. All control variables are included as dummies.

Figure 3 plots the difference in the average GPA across iodine-deficient and iodine-sufficient areas over time, using specification (2). The following control variables are included in the regressions: *Parental characteristics:* Income percentile, years of schooling, age. *Student characteristics:* Age, birth year, gender, high school institution, number of siblings, birth order. All variables are categorical and included in the regressions with dummies for each value. Standard errors are clustered at the high school institution level to allow for correlation in errors between students within the same school. The results are not sensitive to clustering standard errors at the level of treatment (municipality) instead, see appendix table A.2.

As in figure 2, the difference in GPA is stable across years, using both the discrete and continuous measure of treatment. More interestingly, figure 3 exhibits two upward shifts in grades in 1999 and 2002, consistent with the voluntary program in 1998 and the mandatory program in 2000-2001. This suggests that the iodized salt policies produced an immediate improvement in cognitive performance among adolescents.

The magnitude of this effect is shown in table 2, which reports the Difference-in-Differences estimates. When considering the total effect of the two reforms, shown in row 2 of table 2, I

Table 2: The Effect of Salt Iodization on the Grade Point Averages of High School Students

	Discrete	Continuous
First Reform	0.0393	0.0713
	(3.05)	(4.09)
Second Reform	0.0568	0.0882
	(4.08)	(4.52)
Observations	423,881	423,881
r^2	0.1133	0.1133
Adjusted r^2	0.1124	0.1125

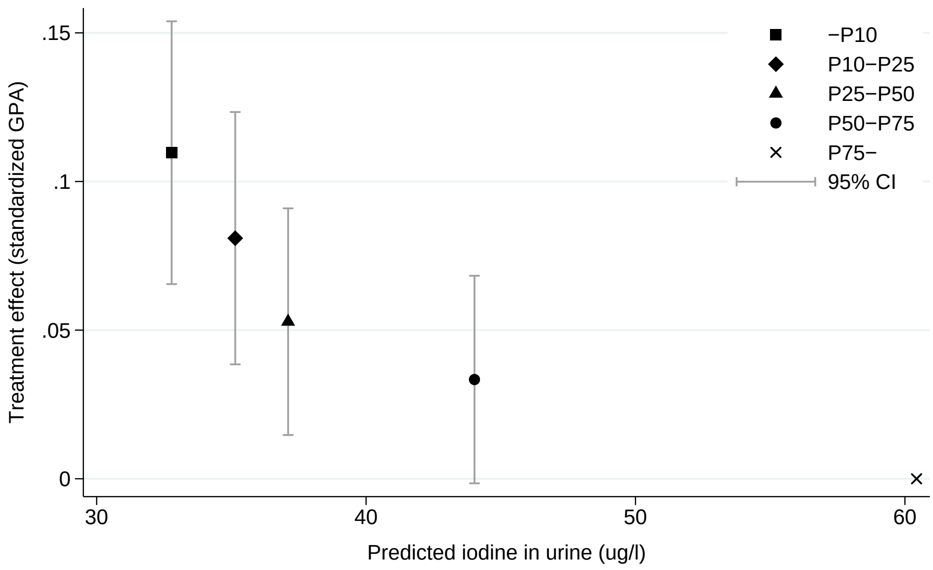
Note: *t*-statistics are reported in parentheses. Standard errors are clustered by high school institution. The estimates reflect the differential change in the standardized GPA of high school students in iodine-deficient vs. iodine-sufficient areas from 1981-1998 to 1999-2001(first row) and 2002-2006(second row). Column 1 shows the results for the discrete treatment variable, column 2 shows the results for the continuous treatment variable. The regressions include the following control variables: Parents: Income percentile, years of schooling, age. Students: Age, birth year, gender, high school institution, number of siblings, birth order. All control variables are included as dummies.

find that salt iodization increases the GPA of high school students in iodine-poor areas by 5.7 percent and 8.8 percent of a standard deviation, for the discrete and continuous measures of treatment. Recall that the discrete treatment variable identifies the effect of salt iodization on students with below median iodine concentrations in drinking water, while the coefficient on the continuous variable reflects the treatment effect on the five percent of students with the lowest iodine concentrations in drinking water. The two coefficients are, therefore, not directly comparable, and the larger coefficient on the continuous treatment variable reflects that the benefits of salt iodization are larger for students that are more deficient.

Table 2 also reports the effect of the first salt iodization reform (row 1), compared to the effect of both reforms (row 2). Two-thirds of the increase in grades is caused by the first and voluntary reform. Hence, even though the first reform only increased iodine intake by 10 $\mu g/day$ (Laurberg et al., 2009), compared to 40 $\mu g/day$ in the second reform, the first reform had a larger impact on cognitive performance than the second reform. This suggests that the relationship between iodine intake and cognitive performance is very concave. To test this, I estimate the benefits of salt iodization across the distribution of initial iodine intake. I measure initial iodine intake using estimates of the relationship between iodine in water and iodine in urine from Pedersen et al. (1999).[15]

[15] The iodine concentration in urine is predicted from estimates of the relationship between iodine in drinking water and iodine in urine from Pedersen et al. (1999): $IodineUrine = 43.2 + 1.7 * IodineWater$, where $IodineWater$ is measured in μg/liter and $IodineUrine$ is measured as μg/day. To convert the predicted iodine in urine to μg/liter, I assume an average adult daily urine output of 1.5 liters.

Figure 4: Heterogeneity by Degree of Iodine Deficiency



Note: The figure plots the change in the average standardized GPA from 1981-1998 (pre-reform) to 2002-2006 (post-reform) of high school students in the 1st to 10th percentile of intake, 10th to 25th percentile of intake, 25th to 50th percentile of intake, and 50th to 75th percentile of intake, relative to students with a predicted iodine intake above the 75th percentile. Iodine intake is predicted using estimates of the relationship between iodine in water and iodine in urine – a measure of iodine intake – from Pedersen et al. (1999). Standard errors are clustered by high school institution. The baseline set of controls is used: Parents: Income percentile, years of schooling, age. Students: Age, birth year, gender, high school institution, number of siblings, birth order. All control variables are included as dummies.

I estimate the change in the average GPA from 1981-1998 (pre-reform) to 2002-2006 (post-reform) of high school students in the 1st to 10th percentile of intake, 10th to 25th percentile of intake, 25th to 50th percentile of intake, and 50th to 75th percentile of intake, relative to students with a predicted iodine intake above the 75th percentile.

The results are shown in figure 4, which plots the estimated treatment effects against the predicted iodine concentration in urine. Severe, moderate and mild iodine deficiencies are defined as iodine concentrations in urine below 20 $\mu g/l$, between 20 and 50 $\mu g/l$, and between 50 and 100 $\mu g/l$ (Andersson et al., 2012), respectively. With a predicted iodine concentration in urine of 60 $\mu g/l$, the base group in the estimation – students above the 75th percentile of intake – are mildly iodine deficient, while the rest of the students suffer from varying degrees of moderate deficiency.

The iodine concentration in urine for students in the 50th to 75th percentile of intake is 44 $\mu g/l$, which is 16 $\mu g/l$ lower than in the base group. The treatment effect for these students is 0.03 standard deviations and not statistically significant. The iodine concentration in urine for students below the 10th percentile of intake is 32 $\mu g/l$. The treatment effect for these students is 0.11 standard deviations – four times larger than the treatment effect for students in the 50th to

Table 3: The Effect of Salt Iodization on the Grade Point Averages of High School Students by Gender

	Baseline	Men	Women
First Reform	0.0713	0.0819	0.0626
	(4.09)	(3.07)	(3.09)
Second Reform	0.0882	0.0630	0.0970
	(4.52)	(2.35)	(4.08)
Observations	423,881	171,601	252,280
r^2	0.1133	0.1096	0.1227
Adjusted r^2	0.1124	0.1076	0.1213

Note: t-statistics are reported in parentheses. Standard errors are clustered by high school institution. The estimates reflect the differential change in the standardized GPA of high school students in iodine-deficient vs. iodine-sufficient areas from 1981-1998 to 1999-2001(first row) and 2002-2006(second row), using the continuous treatment variable. Column 1 shows the baseline results for the entire sample. Columns 2 and 3 present separately estimated coefficients for men and women, respectively. The baseline set of controls is used: Parents: Income percentile, years of schooling, age. Students: Age, birth year, gender, high school institution, number of siblings, birth order. All control variables are included as dummies.

75$^{\text{th}}$ percentile of intake – and highly statistically significant. This pattern is consistent with a very concave relationship between iodine intake and cognitive performance. Furthermore, these results suggest that only moderate to severe iodine deficiency affects cognitive performance.

In appendix figure A.3, I show that the relationship between iodine intake and cognitive performance is sufficiently concave to explain the results in table 2, showing larger treatment effects of the first reform than the second reform.

In the rest of the paper, I focus on estimates using the continuous treatment variable. The continuous treatment variable uses the available variation in iodine intake more efficiently than the discrete treatment variable, and the functional form of the continuous treatment variable accurately fits the observed relationship between the benefits of salt iodization and the initial degree of iodine deficiency, see appendix figure A.2. The results for the discrete treatment variable are qualitatively similar and provided in the appendix.

Heterogeneous Treatment Effects

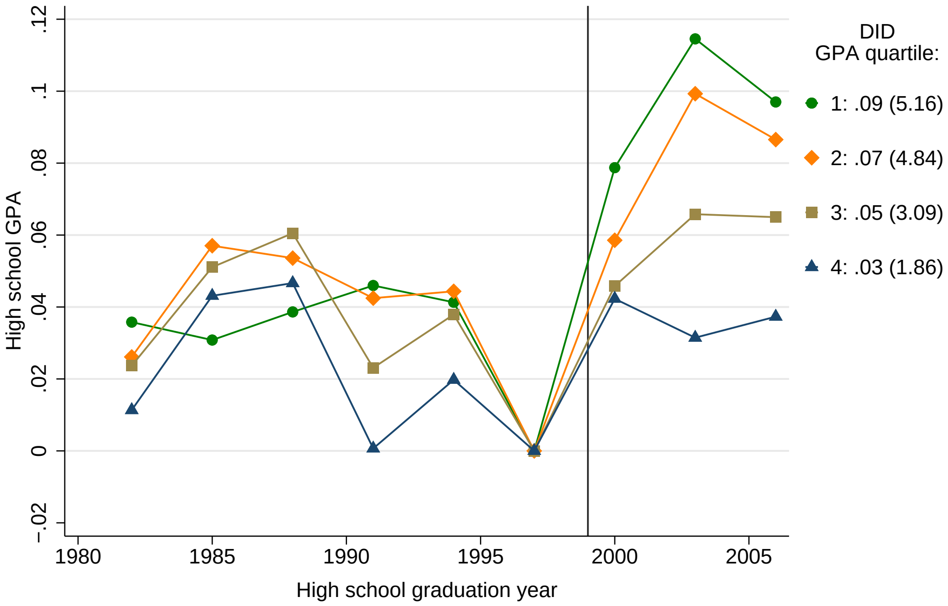
Iodine deficiency disorders are more prevalent among women than men (Pedersen et al., 2002; Vanderpump, 2011), and a number of studies find larger effects of in utero exposure to iodine deficiency among females (Field et al., 2009; Politi, 2010; Adhvaryu et al., 2019). In table 3 I test whether women are also more affected by iodine deficiency in adolescence by splitting the main results by student gender.

The total effect of the two reforms, shown in row 2 of table 3, is larger for girls than boys. The baseline treatment effect of the continuous treatment variable is 8.8 percent of a standard deviation. The treatment effect is 6.3 percent of a standard deviation for boys and 9.7 percent of a standard deviation for girls. The difference across genders is, however, not statistically significant, with a p-value of 0.31. Nonetheless, these results provide suggestive evidence that women benefit more from salt iodization than men.

Effects Across the Distribution of Grades

Figure 5 shows the effect of salt iodization on different parts of the distribution of grades, estimated using quantile regression. I use the Jittering method (Machado and Santos Silva, 2005), which allows for discrete outcome variables, because the recorded GPA of students is rounded to one decimal point.[16,17] The Jittering method is computationally demanding. Therefore, I do not include control variables and I pool years in groups of three.

Figure 5: Effect of Salt Iodization on Different Quartiles of Grade Point Averages



Note: The figure shows the difference in the first, second, third and fourth quartiles of GPA across iodine-deficient and iodine-sufficient areas during the period 1981-2006 using the continuous treatment variable. The coefficients are estimated with quantile regression using the Jittering method with 1,000 repetitions (Machado and Santos Silva, 2005). Years are pooled in groups of three; e.g., the coefficient in 1982 is based on the years 1981,1982, and 1983. Estimates are relative to the baseline level in 1997. Difference-in-Differences estimates are reported to the right. These reflect the effect of salt iodization on each GPA quartile. The Difference-in-Differences models are estimated for the period 1990-2006 to avoid bias from the negative trend in the coefficients over time. No control variables are included in the regressions. t-statistics are reported in parentheses. The t-statistics are based on standard misspecification-robust standard errors. Cluster-robust standard errors have not been developed for the Jittering method. If I instead estimate the coefficients using just one repetition and standard quantile regression with cluster-robust standard errors, the estimates and t-statistics are: 0.09 (3.6), 0.07 (2.5), 0.05 (2.2), 0.03 (1.03) from the first to fourth quartile of grades.

[16] The discrete nature of the outcome variable is particularly problematic in this analysis, because the average treatment effect of 6 % of a standard deviation is smaller than the smallest possible increment in the rounded GPA (0.1 $\approx$ 10 % of a standard deviation).

[17] Figure 5 reports the marginal effects at the average on the smoothed outcome variable (Z in Machado and Santos Silva (2005)).

Figure 5 plots the difference in the first, second, third and fourth quartile of grades across iodine-poor and iodine-rich areas for each year during 1981-2006. As in the main results in figure 3, the coefficients for the four quartiles are all fairly stable during the pre-reform period and then increase in 2000 (1999-2001), when salt iodization is introduced.

There are large differences in the effect of salt iodization across grade quartiles, with larger improvements in the bottom of the distribution of grades. Figure 5 reports the Difference-in-Differences estimates for each quartile. The effect of salt iodization is 0.09, 0.07, 0.05 and 0.03 standard deviations, on the first to fourth quartile of grades. Hence, the effect on the first quartile of grades is 3 times larger than on the fourth quartile of grades. This shows that students in the bottom of the grade distribution benefit most from salt iodization.

Mechanisms

Having established that salt iodization improves cognitive performance in adolescence, I now turn to the question of why this is. There are two mechanisms through which iodine deficiency can affect cognition; 1) through the effect of iodine deficiency on metabolic functioning and brain activity and 2) through brain damage induced by disturbances to normal brain development. I make two separate empirical predictions based on the mechanisms:

Mechanism 1: Metabolic Functioning

If the adverse consequences of iodine deficiency arise through an effect on the metabolism, the treatment effect from salt iodization should be independent of the age at which the students are first treated, as, within this mechanism, only current iodine intake matters for cognitive performance.

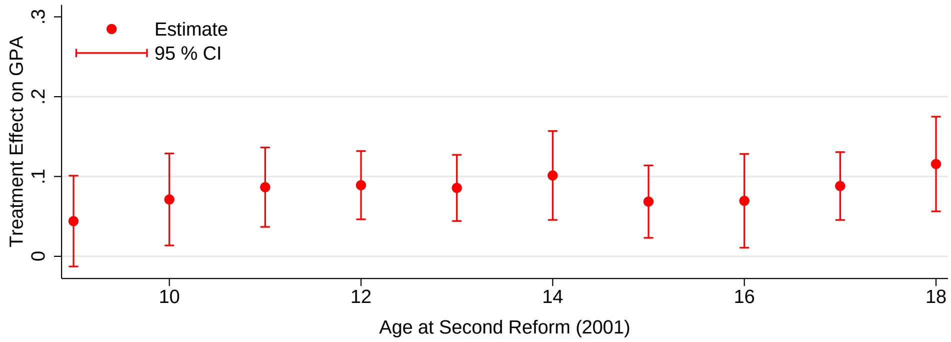
Mechanism 2: Brain Development

If the effects of iodine deficiency work through disturbances to normal brain development, each year a person lives with iodine deficiency during childhood has a direct negative impact on cognitive ability in high school. Therefore, the treatment effect from salt iodization should be higher for students first treated early in life. Specifically, assuming that the incremental damage of one year of iodine deficiency does not depend on the age of the child, I expect the treatment effects from salt iodization to increase linearly as the age at which students are first treated decreases.[18,19]

[18] Importantly, a different and indirect long-run effect could arise from dynamic complementarities and learning effects - improved learning in primary school might lead to higher grades in high school.

[19] This prediction relies on the assumption that the treatment effect from one year of exposure to salt iodization is the same for all ages during childhood. There are several reasons why this might not be the case. (1) For a given degree of deficiency, iodine deficiency is likely to be more detrimental for brain development in early childhood than in late childhood, as brain development is more rapid early in life (Gilmore et al., 2018). However, this only

Figure 6: Treatment Effects by Age at Second Reform



Slope of Treatment Effects and Tests of the Mechanisms

Intercept	Slope	Test 1 (slope=0)	Test 2 (intercept=slope)
0.1005	-0.0038	0.2487	0.0004
(0.0264)	(0.0033)		

Note: The figure plots estimates of the effect of salt iodization on the standardized high school GPA of students first affected by iodized salt at the ages 9-18, using the continuous treatment variable. Each point is a separate Difference-in-Differences estimate for students who graduated in the post-reform years 2002-2011. Students who graduated in 2002-2011 were, on average, 18-9 years old when the second salt iodization reform was implemented in 2001. Hence, the coefficient for age 9 (age 18) in the figure is the Difference-in-Differences estimate for students who graduated in 2011 (2002). The table below figure 6 reports estimates of the slope and intercept of a linear regression going from age 18 to age 9. The intercept is the estimated treatment effect for students first treated at age 18, and the slope is the effect of an additional year of exposure to salt iodization during childhood. Columns 3 and 4 report the p-value of a t-test for whether the slope is different from zero and the p-value of an F-test for whether the intercept is equal to the slope. Standard errors are clustered by high school institution. The baseline set of controls is used: Parents: Income percentile, years of schooling, age. Students: Age, birth year, gender, high school institution, number of siblings, birth order.

I test the predictions of the two competing mechanisms by running the baseline regressions for the extended period 1981-2011. Since high school students are, on average, 19 years old when they graduate, students who finished high school in 2011 were 6 years old when the first reform was implemented in 1998, and 9 years old when the second reform took effect in 2001. Hence, students who graduated in 2011 had been treated (with both reforms) since age 9, whereas students who graduated in 2002 had been treated since age 18. I can, therefore, compare the effect of salt iodization on children first treated at ages 9-18 by estimating separate treatment effects for students who graduated during 2002-2011.

If the common trend assumption holds throughout the period, this straightforward empirical approach is able to identify all cumulative effects of correcting iodine deficiency at ages 9 to 18 on cognitive performance in high school. This encompasses the age interval considered in Gordon

means that treatment effects should increase exponentially rather than linearly as the age at which the students are first treated decreases. (2) The degree of iodine deficiency is not necessarily equally severe throughout childhood. If children aged 9 to 17 are not iodine deficient, that could explain why I do not observe long-run benefits of exposure to salt iodization at these ages. However, for the results in figure 6 to be consistent with long-term effects of iodine deficiency, the students would have to be iodine deficient in only the last year of school before graduation.

et al. (2009) and Zimmermann et al. (2006), who use randomized experiments to study short-run effects of iodine supplementation on cognitive perfomance.

Figure 6 plots the treatment effects for students first treated at ages 9 to 18 (graduated during 2002-2011). I do not find larger effects on high school GPA for students first exposed to iodized salt at an earlier point in life. This suggests that mechanism 1 – in which iodine deficiency affects cognitive performance through metabolic functioning – is responsible for the observed effects of salt iodization. To test this more formally, I estimate the slope and intercept of the treatment effects, starting from students first treated at age 18. The first mechanism implies that treatment effects are constant and the slope of the prediction line is zero. The second mechanism implies that treatment effects should increase linearly from ages 18 to 9, with a slope equal to the intercept - the effect of preventing one year of brain damage and the treatment effect of students first treated at age 18. Figure 6 reports the intercept and slope of the prediction line, the p-value of an F-test for whether the slope is equal to the intercept, and the p-value of a t-test for whether the slope is significantly different from zero. Based on the F-test, I reject that the slope is equal to the intercept, with a p-value of 0.0003. Conversely, I cannot reject that the slope of the prediction line is zero.

These results suggest that while the in utero consequences of iodine deficiency work through disturbances to normal brain development, the postnatal consequences of iodine deficiency documented in this and related papers (Gordon et al., 2009; Zimmermann et al., 2006) are caused by an entirely different biological mechanism. One likely candidate is the effect of iodine deficiency on the metabolism, with consequences for brain activity, memory, and concentration.

6 Robustness

The two main threats to the identification strategy are contemporaneous shocks to determinants of grades and endogenous selection into high school across years. As a first step, I address both of these issues by including an extra set of control variables in the regressions. Table 4 presents the results of this sensitivity analysis. Column one replicates the previous results using baseline controls. Column two adds labor market participation variables for parents. These include dummies indicating whether at least one parent is unemployed, retired, on disability pension, on temporary leave, or not in the work force for other reasons. In column three I extend this list with additional family characteristics, including dummies for whether parents are married to each other, the number of living parents, and whether the child lives with a parent. The coefficients are not sensitive to the inclusion of either of these covariate groups. This is not entirely surprising as these variables capture the same characteristics of the children as the

Table 4: Robustness to Extra Control Variables

	(1)	(2)	(3)	(4)	(5)
First Reform	0.0713	0.0706	0.0703	0.0673	0.0675
	(4.09)	(4.05)	(4.04)	(4.30)	(4.30)
Second Reform	0.0882	0.0878	0.0880	0.0797	0.0806
	(4.52)	(4.53)	(4.53)	(4.55)	(4.57)
Baseline	X	X	X	X	X
Labor Market		X	X	X	X
Family			X	X	X
Birth					X
Observations	423,881	423,881	423,881	180,718	180,718
r^2	0.1133	0.1136	0.1138	0.1300	0.1301
Adjusted r^2	0.1125	0.1127	0.1129	0.1283	0.1283

Note: *t*-statistics are reported in parentheses. Standard errors are clustered by high school institution. The estimates reflect the differential change in the standardized GPA of high school students in iodine-deficient vs. iodine-sufficient areas from 1981-1998 to 1999-2001(first row) and 2002-2006(second row), using the continuous treatment variable. Baseline controls: Parents: Income percentile, years of schooling, age. Students: Age, birth year, gender, high school institution, number of siblings, birth order. Labor market controls: Dummies for whether either parent is unemployed, retired, on disability pension, on temporary leave, or not in the work force for other reasons. Family controls: Dummies for whether parents are married to each other, number of living parents, and whether the student lives with a parent. Birth controls: Birth weight and birth length dummies. Estimates in columns 4 and 5 are based on a restricted sample: Years 1995-2006 and student age at graduation below 22.

baseline controls, namely socioeconomic status. Nonetheless, this suggests that the estimates are not driven by changes in the parents' labor market outcomes or family characteristics, whether due to asymmetric shocks or endogenous selection.

In column five, I include birth weight dummies and birth length dummies. Recent research shows that a considerable part of the variation in abilities and health in adulthood is determined even before birth (Almond and Currie, 2011). Hence, by including birth outcomes I am partly able to control for changes in the underlying endowments of the students. Birth outcomes are only recorded for children born after 1973, and, therefore, the regressions using these focus on the years 1995-2006 and exclude students older than 22 at graduation – less than 0.5% of the students are older than 22 at graduation. In column four of table 4, I report the estimates from this restricted sample, but without including birth controls. The coefficients are slightly smaller in this sample, but they are not significantly different from the baseline estimates. Including birth controls in column 5 does not affect the estimates, suggesting that the results are robust to controlling for this measure of underlying abilities.

Because the treatment group is concentrated in a few areas, the results might be sensitive to regional shocks to unobservable characteristics of the students. To address this concern, I include region-year fixed effects in the regressions. In doing so, the effect of the reforms is identified using only within-region variation in treatment, which eliminates the influence of any region-

Table 5: Robustness to Geographical Control Variables

	(1)	(2)	(3)	(4)
First Reform	0.0713	0.0729	0.0735	0.0527
	(4.09)	(4.10)	(3.75)	(3.13)
Second Reform	0.0882	0.0801	0.0830	0.0569
	(4.52)	(3.96)	(3.69)	(3.03)
Baseline	X	X	X	X
DEGURBA 1		X		
DEGURBA 2			X	
West Denmark				X
Observations	423,881	423,881	423,881	423,881
r^2	0.1133	0.1135	0.1138	0.1134
Adjusted r^2	0.1125	0.1126	0.1126	0.1125
r^2 of Treat	0.0000	0.0794	0.1493	0.2506

Note: t-statistics are reported in parentheses. Standard errors are clustered by high school institution. The estimates reflect the differential change in standardized GPA of high school students in iodine-deficient vs. iodine-sufficient areas from 1981-1998 to 1999-2001(first row) and 2002-2006(second row), using the continuous treatment variable. Baseline controls: Parents: Income percentile, years of schooling, age. Students: Age, birth year, gender, high school institution, number of siblings, birth order. DEGURBA 1: Dummies for the three categories in Eurostat's DEGURBA classification interacted with graduation year dummies. DEGURBA 2: Dummies for the five categories in Statistics Denmark's extended DEGURBA classification interacted with graduation year dummies. West Denmark: Dummy for living in Jutland or Funen (West Denmark) interacted with graduation year dummies.

specific shocks to determinants of grades. I use three different geographical control variables; the Degree of Urbanization (DEGURBA) classification from Eurostat, an extended DEGURBA classification created by Statistics Denmark, and a dummy indicating whether the student lives in West or East Denmark.[20] I use the West Denmark split because the majority of treatment group municipalities are placed in West Denmark, see figure 1.

Table 5 presents the regression estimates. As reported in the summary statistics in table 1, students in the treatment group are more likely to live in rural areas than students in the control group. To quantify how much of the variance in treatment assignment is actually explained by these differences, the last row of table 5 reports the r-squared from a regression of the continuous treatment variable on the geographical control variables.

The degree of urbanization classifications explain between 8 and 15 percent of the variation in the continuous treatment variable. Even though this means that a large part of the variance in treatment assignment comes from comparisons across rural and urban areas, the results are not sensitive to excluding this source of variation and using only within-rural/urban area variation

[20] The DEGURBA classification by Eurostat splits municipalities into three categories; (1) densely populated areas, (2) intermediate density areas and (3) thinly populated areas, http://ec.europa.eu/eurostat/ramon/miscellaneous/index.cfm?TargetUrl=DSP_DEGURBA. The extended DEGURBA classification by Statistics Denmark, splits intermediate density areas and thinly populated areas in Eurostat's classification into four groups based on the number of inhabitants – a total of five degrees of urbanization. West Denmark is defined as Jutland and Funen.

to identify the treatment effect. Regardless of the urbanization classification used, the estimates are close to the baseline results, albeit slightly smaller. The smaller coefficients may reflect that including the geographical controls worsens the attenuation bias from measurement error in the treatment variables.[21]

This is particularly likely in column 4 of table 5, which reports the estimates using only within-West/East Denmark variation in treatment. The West Denmark dummy alone explains 25 percent of the variation in the continuous treatment variable. The estimated coefficients are smaller than the baseline estimates but they remain economically and statistically significant. The total effect of the two reforms is 5.7 percent of a standard deviation.

Sample Selection

High school is voluntary in Denmark and about 30 percent of a cohort choose to enroll in the STX program after finishing lower/middle secondary school.[22] Since the data only contains information on the GPA of STX graduates, differential selection into high school across years might affect the results.

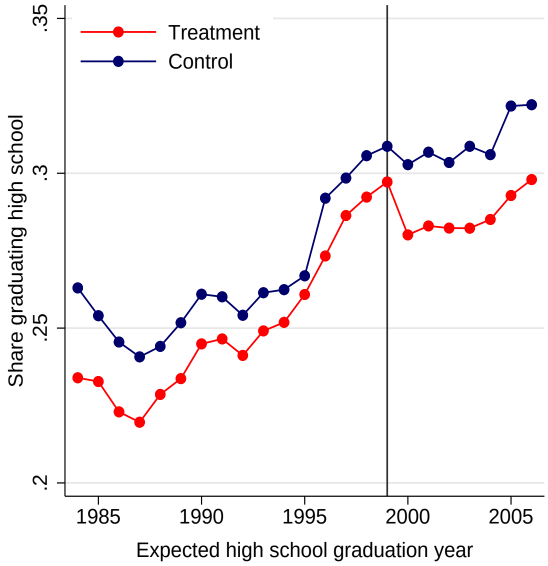
Figure 7A plots the share of lower/middle secondary school graduates that finish an STX high school education in treatment and control group municipalities, defined using the discrete treatment variable. I plot the graduation rates by the predicted graduation year to show when we can expect selection into high school to affect average grades. The predicted graduation year is set to three years after lower/middle secondary school graduation, at which point 90 percent of high school students graduate.

Throughout the data period, children in treatment group municipalities are less likely to obtain an STX high school education than children in control group municipalities. The gap narrows over time and then broadens in 2000, with a larger drop in graduation rates in treatment group municipalities. If marginal high school students would have achieved grades below those of the average graduate, the widening of the gap in graduation rates in 2000 may produce a mechanical increase in grades in the treatment group relative to the control group. However, since the effect on grades in the main results, shown in panel B, starts in 1999, the results cannot be explained by a change in graduation rates in 2000.

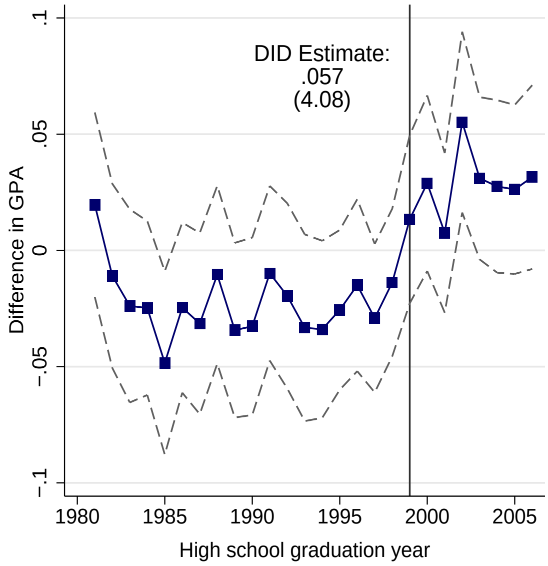
[21] The treatment variables are measured with substantial error. Even in the unlikely case that the ground water samples perfectly predict actual iodine intake from drinking water, there are many other determinants of iodine deficiency.

[22] In Denmark, school attendance is compulsory until the end of year 9. Children attend primary school ('Folkeskole') from kindergarten to year 9, which encompasses primary and lower/middle secondary education. High school refers to years 10 to 12.

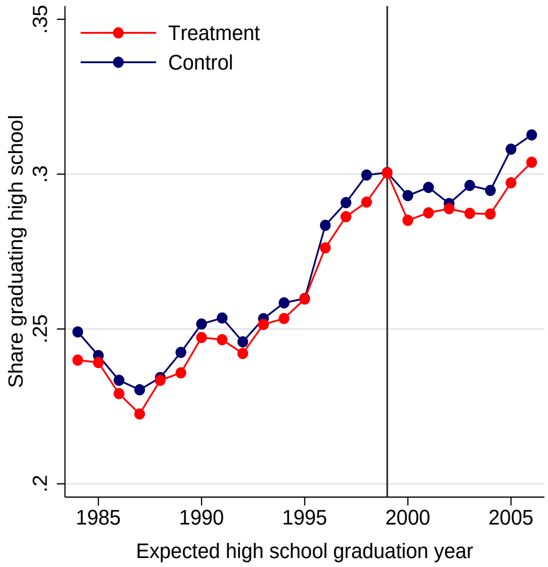
Figure 7: Sample Selection



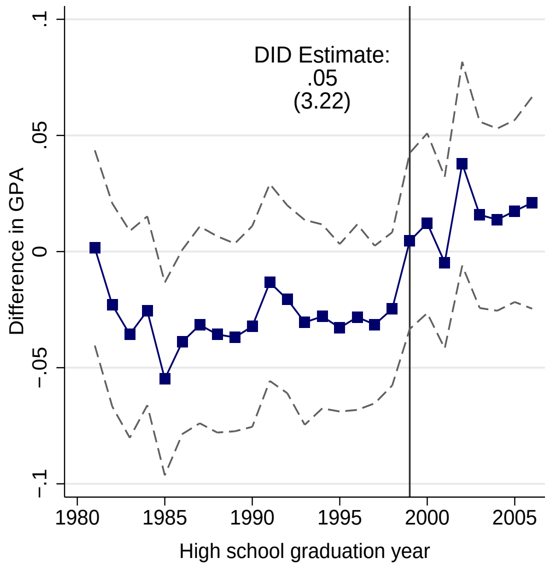
A Sample Selection, Raw



B Effect on GPA, Raw



C Sample Selection, Matched



D Effect on GPA, Matched

Note: Panel A reports the share of lower/middle secondary school graduates in treatment and control group municipalities that graduate from an STX high school education. I plot this for each expected high school graduation year (three years after leaving lower/middle secondary school) during the period 1984-2006. Panel B shows baseline estimates of the difference in average standardized GPA between the treatment and control groups for each year during 1981-2006, using the discrete treatment variable. The dotted grey lines represent 95% confidence intervals, using standard errors clustered by high school institution. The baseline set of controls is used: Parents: Income percentile, years of schooling, age. Students: Age, birth year, gender, high school institution, number of siblings, birth order. The vertical line at year 1999 represents the introduction of iodized salt. Panels C and D replicate panels A and B, but on a matched sample. The matching is based on Inverse Probability Weighting. The propensity score P is estimated with Probit, using high school enrollment rates for each municipality and for each year as explanatory variables. I take the propensity score as given in the estimation of standard errors. The weights are $\frac{1}{P}$ for the treatment group and $\frac{1}{1-P}$ for the control group.

In appendix figure A.4, I show that the widening gap in graduation rates in 2000 is caused by a reduction in the number of schools offering the business-oriented HHX high school program in control group municipalities.[23] With fewer schools offering HHX programs, more individuals chose to enroll in the STX program, making the 2000 drop in STX high school graduation rates smaller in control group municipalities. If I drop municipalities that experienced a school closure during this period, the levels and trends in graduation rates are very similar across treatment and control group municipalities and the original results on grades are unchanged, see figure A.4.

To show more formally that sample selection is not an issue, I match treatment and control municipalities based on STX high school graduation rates. If the results are caused by sample selection, the effect on grades would be zero if graduation rates were identical in the two groups. By matching on graduation rates I can test this scenario and evaluate whether sample selection drives the results.

I use Inverse Probability Weighting (Mansournia and Altman, 2016) to conduct the matching. I estimate the propensity score by Probit and use STX high school enrollment rates in each municipality and for each expected graduation year during 1984-2006 as explanatory variables.[24] The results are shown in figure 7, panels C and D.

The matching is accurate. As shown in figure 7C, there is no visible gap in graduation rates between treatment and control group municipalities in the matched sample. More importantly, the drop in 2000 is similar in the two groups and there is no widening of the gap from 2000 and onward. Nonetheless, the effect on grades, shown in panel D, persists. In fact, the pre-trends and the effects of the reforms are even more striking in the matched sample. Furthermore, the estimated treatment effect is close to the baseline effect for the discrete treatment variable reported in panel B. This shows that sample selection cannot explain the results of the empirical analysis.

External Validity

This paper estimates the causal effect of salt iodization on cognitive performance among Danish high school students. A natural question is whether this sample is representative of the general

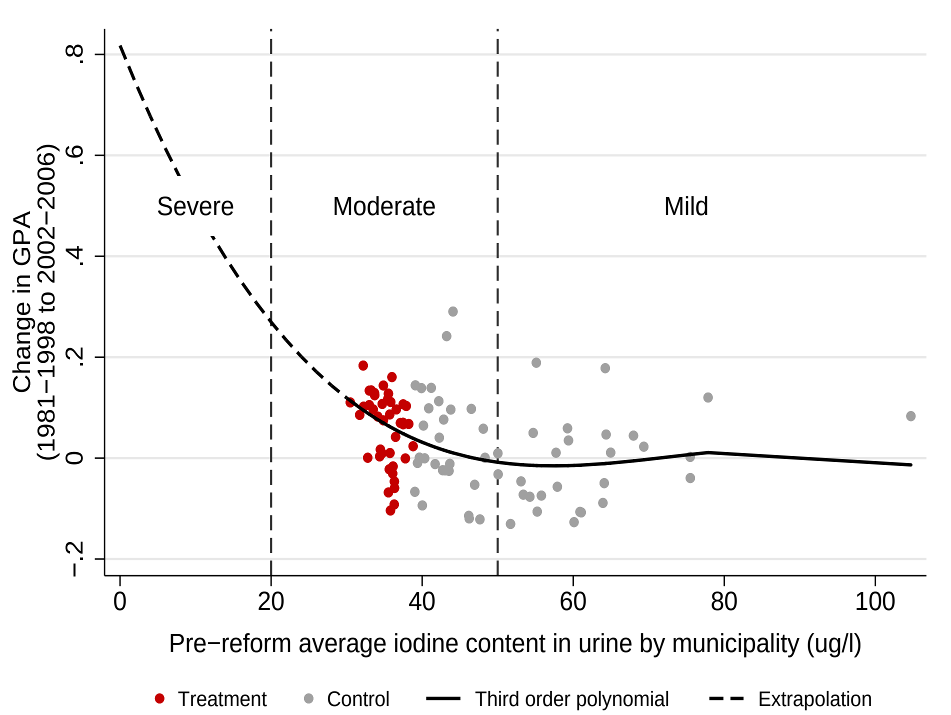
[23]HHX is the second-largest high school program and around 10 percent of a lower/middle secondary school cohort enroll in the HHX program after graduation. The reduction in the number of high schools offering HHX programs in control group municipalities around 2000 is most likely due to relatively small cohorts in those years.

[24]I match on enrollment in high school rather than completion because the probability of dropping out of high school can be endogenous to treatment. The estimates are based on the restricted period 1984-2006 because I cannot identify high school enrollment before 1982, and because the results are plotted by expected graduation year, which is three years after enrollment.

population in Denmark and how the results for Denmark relate to salt iodization policies in other parts of the world.

Because upper secondary education is voluntary in Denmark and most high school graduates go on to complete a tertiary education, high school students represent a positively selected sample of higher-achieving individuals. Since high-achieving students benefit less from salt iodization than low-achieving students, see figure 5, I expect larger estimates for the general population. Hence, the estimates for high school students most likely represent lower bounds on the population-wide benefits of salt iodization.

Figure 8: Predicted Gains from Correcting Iodine Deficiency by Degree of Deficiency



Note: The figure plots the change in average standardized GPA from 1981-1998 to 2002-2006 for each municipality in the sample relative to a synthetic iodine-sufficient (150 μg/liter) municipality. The x-axis shows the iodine concentration in urine (a measure of iodine intake) in each municipality as predicted by the iodine concentration in drinking water. The solid and dashed line is the prediction and extrapolation of a third order polynomial. The dashed lines represents thresholds for mild, moderate and severe iodine deficiencies, see Andersson et al. (2012).

The results in this paper are specific to the degree of iodine deficiency present in Denmark prior to salt iodization. The Danish population was mildly to moderately deficient before the reforms were implemented. To give some indication of the benefits of salt iodization in other countries, I perform an extrapolation. I do this based on the relationship between the change in average GPA over time and the pre-existing level of iodine deficiency across municipalities, measured using the predicted iodine concentration in urine.[15]

Figure 8 plots the results. The dots represent the change in average standardized GPA from 1981-1998 to 2002-2006 in each municipality in the treatment and control groups, relative to a synthetic iodine-sufficient (150 μg/liter) municipality. The solid black line in figure 8 shows the predicted relationship between initial iodine deficiency and the increase in average GPA due to salt iodization, using a third order polynomial. The dashed line is an extrapolation from this prediction.

In line with the findings of the paper, the predicted treatment effect in figure 8 is increasing in the severity of iodine deficiency. Moreover, because Danes were mildly to moderately iodine-deficient prior to the reforms, the treatment effects observed in the paper are small compared to the prediction for more severely deficient countries. For moderate iodine deficiency, the predicted treatment effect is 0.13 standard deviations, and in environments with severe iodine deficiency the predicted treatment effect is 0.50 standard deviations.

According to estimates from Andersson et al. (2012), 15.9% of school-age children are mildly iodine deficient, 8.1% are moderately iodine deficient, and 5.2% are severely iodine deficient globally. Hence, the postnatal benefits of salt iodization are likely to be much larger in other populations.

7 Conclusion

The worldwide adoption of iodized salt over the past three decades is one of the most successful public health interventions in recent times. The focus of these efforts has been to prevent mental retardation caused by in utero exposure to maternal iodine deficiency. While this is the most severe consequence of iodine deficiency, my analysis shows that salt iodization policies benefit a much broader group of individuals.

Using the introduction of iodized salt in Denmark over the period 1998-2001, I find that salt iodization improves cognitive performance among adolescents. I show that this effect most likely arises from the contemporaneous effect of iodine deficiency on metabolic functioning and brain activity. As iodine is crucial for the metabolism in all stages of life, this suggests that similar benefits of salt iodization may be found for adults. If so, the aggregate societal benefits of salt iodization policies would be considerably larger than previously thought.

While the use of iodized salt has reduced the incidence of iodine deficiency dramatically, about one-third of the world population remain iodine deficient (Andersson et al., 2012). Hence, there is still a large untapped economic potential in eradicating iodine deficiency. My results are especially relevant for other European countries, where iodine deficiency is not considered a serious health concern, despite the region having one of the highest rates of deficiency and the lowest rate of salt iodization (WHO, 2007). In developing countries, where severe iodine deficiency is more prevalent, my estimates add to the already large expected benefits of salt iodization.

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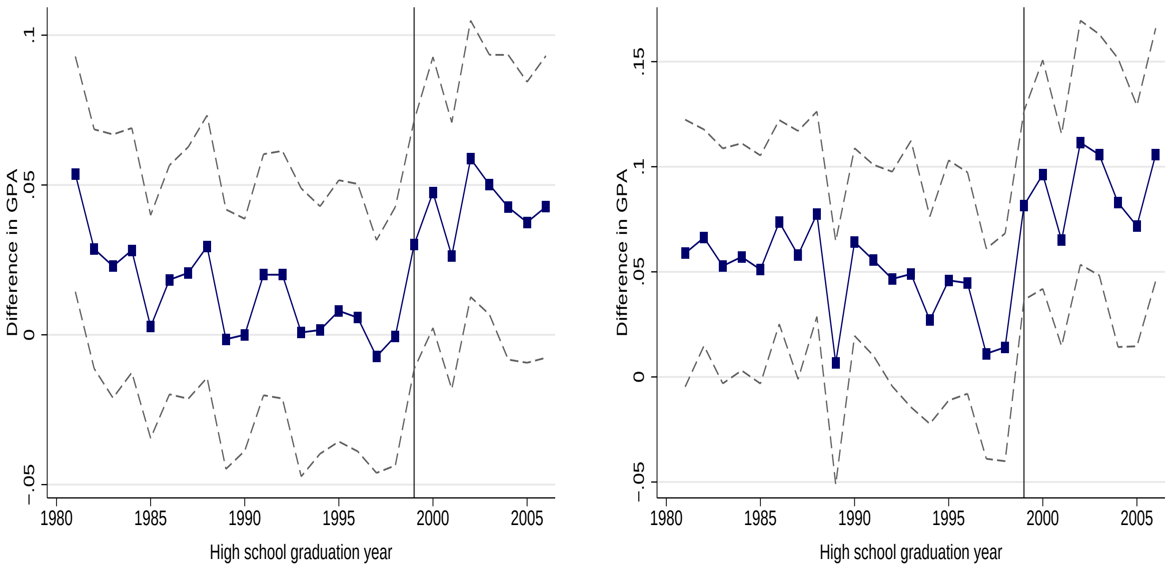
A Appendix

Figure A.1: Difference in Average Grade Point Averages Across Iodine-Deficient and Iodine-Sufficient Areas Over Time Without Control Variables



A Discrete

B Continuous

Note: The figure plots the difference in average standardized GPA between iodine-deficient and iodine-sufficient areas for each year during 1981-2006. The dotted grey lines represent 95% confidence intervals, using standard errors clustered by high school institution. Panel A shows the results for the discrete treatment measure, panel B shows the results for the continuous treatment measure. No control variables are included in the regressions. The vertical line at year 1999 represents the introduction of iodized salt.

Table A.1: The Effect of Salt Iodization on the Grade Point Averages of STX and HF Students

	Discrete		Continuous	
	Baseline	With HF	Baseline	With HF
First Reform	0.0393	0.0343	0.0713	0.0570
	(3.05)	(3.02)	(4.09)	(4.02)
Second Reform	0.0568	0.0502	0.0882	0.0802
	(4.08)	(4.16)	(4.52)	(5.08)
Observations	423,881	612,793	423,881	612,793
r^2	0.1133	0.1031	0.1133	0.1031
Adjusted r^2	0.1124	0.1022	0.1125	0.1022

Note: t-statistics are reported in parentheses. Standard errors are clustered by high school institution. The estimates reflect the differential change in standardized GPA of high school students in iodine-deficient vs. iodine-sufficient areas from 1981-1998 to 1999-2001(first row) and 2002-2006(second row). Columns 1 and 2 present baseline estimates for STX students. Columns 3 and 4 show results for the pooled sample of STX and HF students. The baseline set of controls is used: Parents: Income percentile, years of schooling, age. Students: Age, birth year, gender, high school institution, number of siblings, birth order. All variables are included as dummies.

Table A.2: Robustness of Main Results to Choice of Standard Errors

	Discrete		Continuous	
SE clustered by	High School ID	Muni	High School ID	Muni
First Reform	0.0393	0.0393	0.0713	0.0713
	(3.05)	(3.14)	(4.09)	(4.48)
Second Reform	0.0568	0.0568	0.0882	0.0882
	(4.08)	(4.28)	(4.52)	(4.57)
Observations	423,881	423,881	423,881	423,881
r^2	0.1133	0.1133	0.1133	0.1133
Adjusted r^2	0.1124	0.1124	0.1125	0.1125

Note: *t*-statistics are reported in parentheses. In columns 1 and 3, standard errors are clustered by high school institution. In columns 2 and 4, standard errors are clustered by municipality of residence. The estimates reflect the differential change in standardized GPA of high school students in iodine-deficient vs. iodine-sufficient areas from 1981-1998 to 1999-2001(first row) and 2002-2006(second row). The regressions include the following control variables: Parents: Income percentile, years of schooling, age. Students: Age, birth year, gender, high school institution, number of siblings, birth order. All control variables are included as dummies.

Functional Form Assumptions

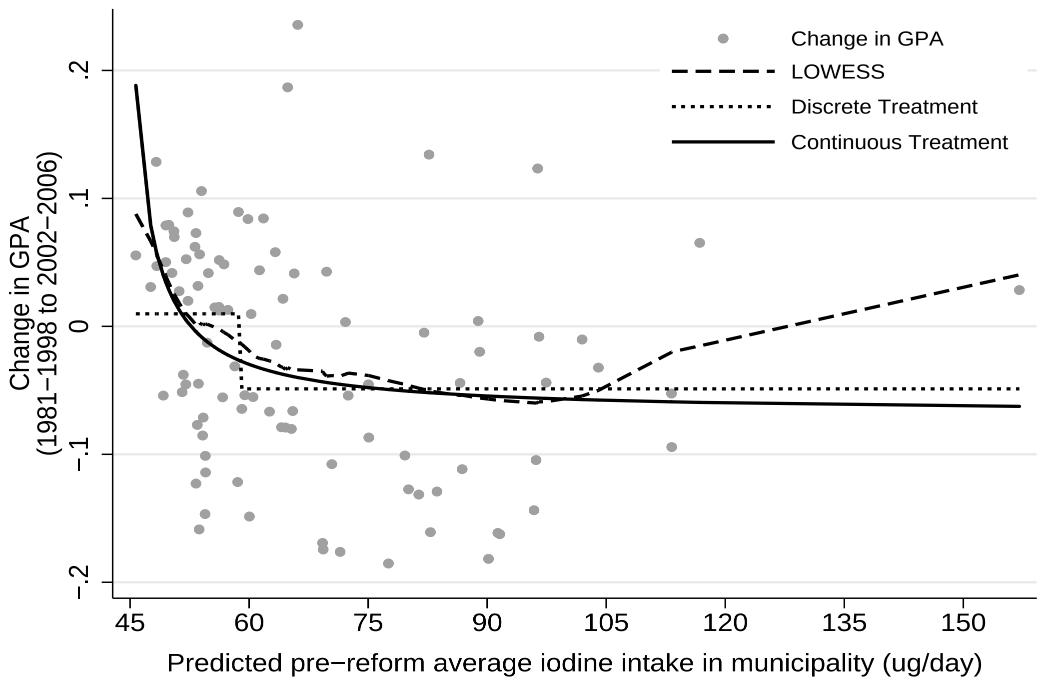
Figure A.2 plots the change in average GPA from 1981-1998 to 2002-2006 against the expected pre-reform level of iodine intake for each municipality in the sample.[25] I include a LOWESS (Locally Weighted Scatterplot Smoothing) line to draw inferences about the functional form of the relationship between iodine deficiency and cognitive performance. In line with previous results, the estimates show that iodine-deficient areas benefited most from salt iodization. Figure A.2 also plots the predictions of the two treatment variables used in the main analysis. The discrete treatment variable measures the average difference in the change in GPA between individuals living in areas with iodine concentrations in drinking water above and below the median. Hence, this variable does not assume a specific functional form. The continuous treatment variable, however, is based on the assumption that the GPA of high school students is linearly increasing in the log of iodine concentrations in drinking water. Despite this strong assumption, the imposed relationship between iodine deficiency and GPA, based on this variable, is close to the LOWESS estimate. This suggests that the functional form of the continuous treatment variable is a good approximation of the true functional form of the relationship between iodine deficiency and GPA.

In the empirical analysis, I normalize the continuous treatment variable to reflect the difference between individuals in the 5^{th} and 95^{th} percentile of iodine concentrations in drinking water. Therefore, the coefficients of the discrete and continuous treatment variables are not directly comparable. If, for both treatment variables, we instead compare the predicted treatment

[25] I calculate the expected iodine intake from the relationship between iodine in urine (a common measure of iodine intake) and iodine in drinking water in Denmark, reported by Pedersen et al. (1999): $IodineUrine = 43.2 + 1.7 * IodineWater$. $IodineWater$ is measured in μg/liter and $IodineUrine$ is measured as μg/day.

effect for individuals with below median iodine concentrations in drinking water, the estimated effect of salt iodization is almost identical.

Figure A.2: Test of Functional Form Assumptions



Relationship Between Iodine Deficiency and Change in GPA

The voluntary salt fortification program in 1998 increased iodine intake by 10 μg/day, compared to 40 μg/day in the mandatory second reform (Laurberg et al., 2009). Nonetheless, as shown in table 2, the effect on the GPA of high school students is larger in the first reform than in the second reform. In this section, I test whether this observation is explained by the concave relationship between iodine intake and cognitive performance.

Figure A.3 plots a LOWESS prediction of the relationship between initial iodine intake and the change in GPA from 1981-1998 (pre-reform) to 2001-2006 (post-reform), for each municipality in the sample.[25] The estimates are normalized to zero for values above 100 μg/day, which is the lower bound of the recommended range of iodine intake. The LOWESS line represents the predicted combined treatment effect of the two salt iodization reforms. Assuming this prediction is accurate, I can estimate the expected treatment effect of the second iodization reform, given that the first reform has already been implemented. I do this by considering what the LOWESS fit would look like if all individuals consumed 10 μg/day more iodine initially, which is the increase in iodine intake caused by the first reform. This extrapolation, which is basically the standard LOWESS estimate moved 10 μg to the left, is illustrated as the red line in figure A.3.

Clearly, the expected gains of the second reform are markedly smaller than the total effect of salt iodization. This is because the largest treatment effects in the most severe range of deficiency accrue to the first reform. To quantify the difference between the expected effect of the second reform and the two reforms combined, I use the discrete treatment variable and compare the predicted treatment effect across the treatment and control groups, illustrated by the black dashed line in figure A.3. The result is also reported in figure A.3. The total effect of the two salt iodization reforms is 0.048 standard deviations, while the expected effect of the second reform is 0.018 standard deviations. Hence, the relationship between iodine intake and GPA is sufficiently concave to explain that the effect of the first reform is larger than the second reform.

Figure A.3: Concavity of the Relationship Between Iodine Deficiency and GPA

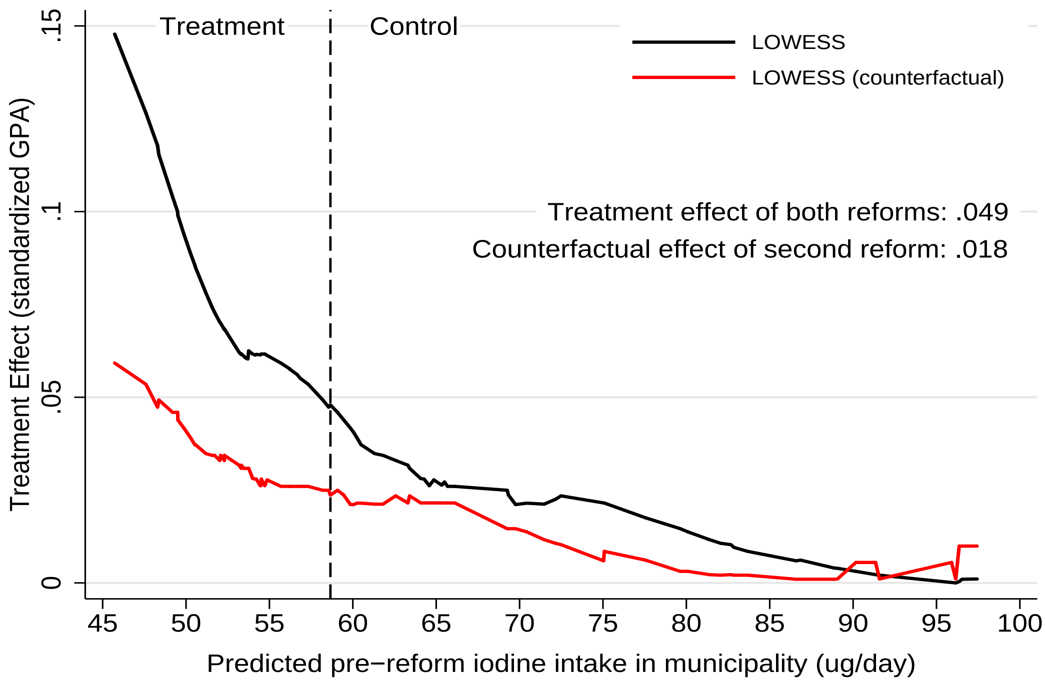
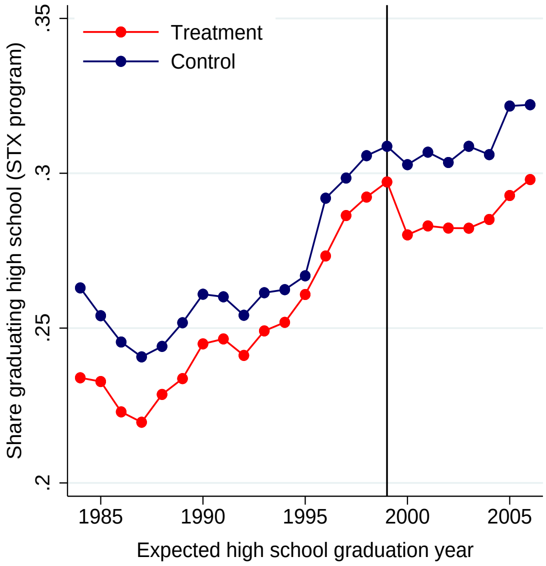
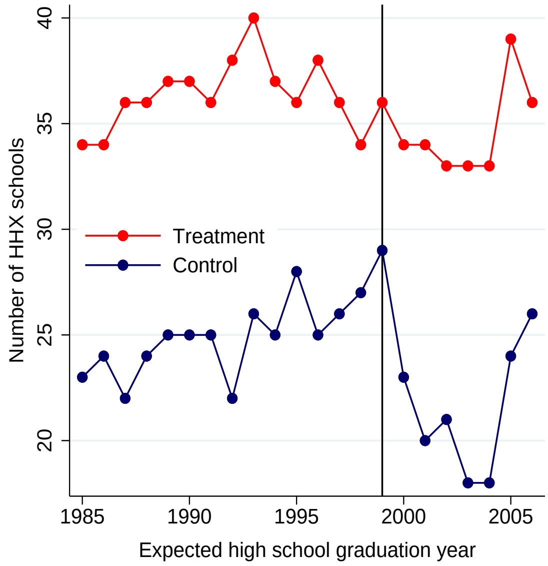


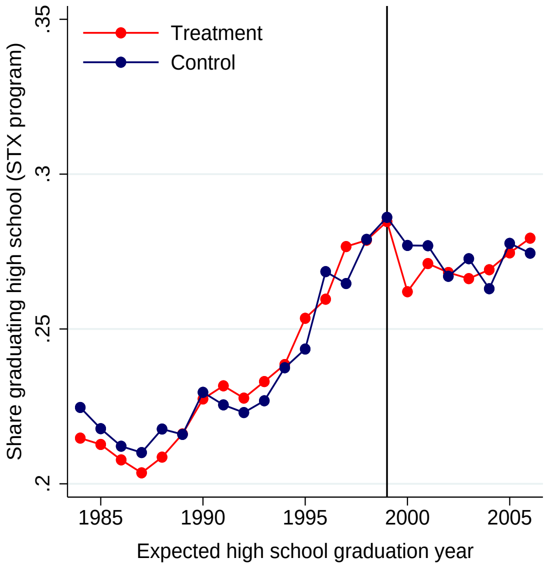
Figure A.4: Explanation for Differential Change in Graduates Rates in 2000



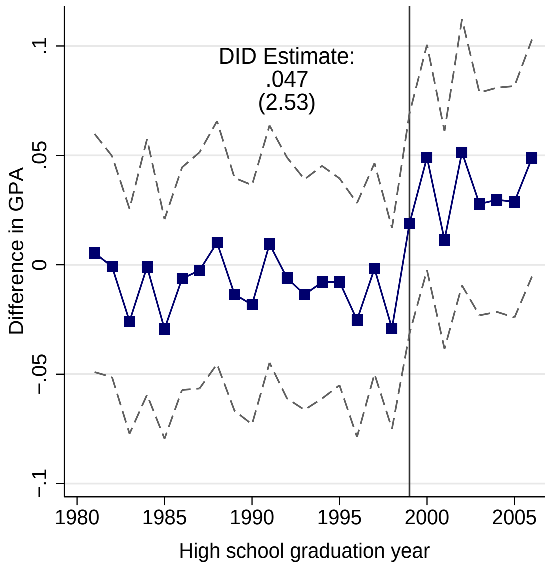
A Sample Selection



B Number of HHX Schools Over Time



C Sample Selection, No School Closure Sample



D Effect on GPA, No School Closure Sample

Note: Panel A reports the share of lower/middle secondary school graduates in treatment and control group municipalities, defined using the discrete treatment variable, that graduate from an STX high school education. I plot this for each expected high school graduation year (three years after leaving lower/middle secondary school) during 1984-2006. Panel B shows the number of HHX high schools in treatment and control group municipalities over time. A HHX school is defined as an institution in which 20 or more students start a HHX program in a given year. To match the other graphs, the number of HHX schools is plotted against the expected graduation year of the students, which is three years after enrollment. Panel C plots the share of lower/middle secondary school graduates in treatment and control group municipalities that graduate from high school, excluding municpalities where at least two students have historically attended a HHX school that closed in 1996 or 1997 (affecting graduation rates in 1999 and 2000). This restriction drops about 20 percent of the municipalities and 40 percent of the STX graduates from the sample. Panel D shows the baseline results on grades using this restricted sample. t-statistics are reported in parentheses. Standard errors are clustered by high school institution.

Figures and Tables Using the Discrete Treatment Variable

Table A.3: The Effect of Salt Iodization on the Grade Point Averages of High School Students By Gender

	Baseline	Men	Women
First Reform	0.0393	0.0485	0.0325
	(3.05)	(2.36)	(2.18)
Second Reform	0.0568	0.0418	0.0620
	(4.08)	(2.08)	(4.47)
Observations	423,881	171,601	252,280
r^2	0.1133	0.1096	0.1226
Adjusted r^2	0.1124	0.1075	0.1212

Note: t-statistics are reported in parentheses. Standard errors are clustered by high school institution. The estimates reflect the differential change in the standardized GPA of high school students in iodine-deficient vs. iodine-sufficient areas from 1981-1998 to 1999-2001(first row) and 2002-2006(second row), using the discrete treatment variable. Column 1 shows the baseline results for the entire sample. Column 2 and 3 present separately estimated coefficients for men and women, respectively. The baseline set of controls is used: Parents: Income percentile, years of schooling, age. Students: Age, birth year, gender, high school institution, number of siblings, birth order. All control variables are included as dummies.

Table A.4: Robustness to Extra Control Variables

	(1)	(2)	(3)	(4)	(5)
First Reform	0.0393	0.0391	0.0392	0.0412	0.0412
	(3.05)	(3.05)	(3.06)	(3.18)	(3.17)
Second Reform	0.0568	0.0569	0.0572	0.0567	0.0571
	(4.08)	(4.10)	(4.13)	(4.07)	(4.08)
Baseline	X	X	X	X	X
Labor Market		X	X	X	X
Family			X	X	X
Birth					X
Observations	423,881	423,881	423,881	180,718	180,718
r^2	0.1133	0.1136	0.1137	0.1300	0.1301
Adjusted r^2	0.1124	0.1127	0.1129	0.1283	0.1283

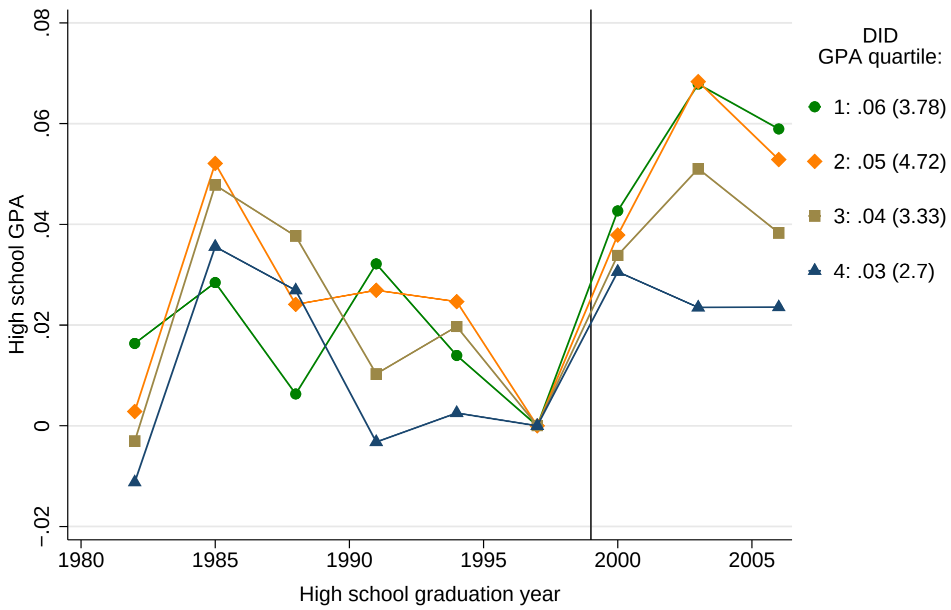
Note: t-statistics are reported in parentheses. Standard errors are clustered by high school institution. The estimates reflect the differential change in the standardized GPA of high school students in iodine-deficient vs. iodine-sufficient areas from 1981-1998 to 1999-2001(first row) and 2002-2006(second row), using the discrete treatment variable. Baseline controls: Parents: Income percentile, years of schooling, age. Students: Age, birth year, gender, high school institution, number of siblings, birth order. Labor market controls: Dummies for whether either parent is unemployed, retired, on disability pension, on temporary leave, or not in the work force for other reasons. Family controls: Dummies for whether parents are married to each other, number of living parents, and whether the student lives with a parent. Birth controls: Birth weight and birth length dummies. Estimates in columns 4 and 5 are based on a restricted sample: Years 1995-2006 and student age at graduation below 22.

Table A.5: Robustness to Geographical Control Variables

	(1)	(2)	(3)	(4)
First Reform	0.0393	0.0391	0.0380	0.0227
	(3.05)	(3.04)	(2.88)	(1.72)
Second Reform	0.0568	0.0524	0.0504	0.0331
	(4.08)	(3.83)	(3.73)	(2.16)
Baseline	X	X	X	X
DEGURBA 1		X		
DEGURBA 2			X	
West Denmark				X
Observations	423,881	423,881	423,881	423,881
r^2	0.1133	0.1135	0.1137	0.1134
Adjusted r^2	0.1124	0.1125	0.1126	0.1125
r^2 of Treat	0.0000	0.0339	0.0508	0.2402

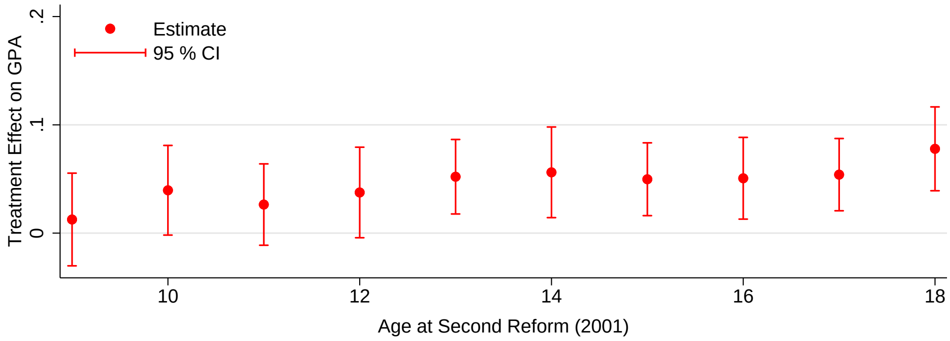
Note: t-statistics are reported in parentheses. Standard errors are clustered by high school institution. The estimates reflect the differential change in standardized GPA of high school students in iodine-deficient vs. iodine-sufficient areas from 1981-1998 to 1999-2001(first row) and 2002-2006(second row), using the discrete treatment variable. Baseline controls: Parents: Income percentile, years of schooling, age. Students: Age, birth year, gender, high school institution, number of siblings, birth order. DEGURBA 1: Dummies for the three categories in Eurostat's DEGURBA classification interacted with graduation year dummies. DEGURBA 2: Dummies for the five categories in Statistics Denmark's extended DEGURBA classification interacted with graduation year dummies. West Denmark: Dummy for living in Jutland or Funen (West Denmark) interacted with graduation year dummies.

Figure A.5: Effect of Salt Iodization on Different Quartiles of Grade Point Averages



Note: The figure shows the difference in the first, second, third and fourth quartiles of GPA across iodine-deficient and iodine-sufficient areas during the period 1981-2006, using the discrete treatment variable. The coefficients are estimated with quantile regression using the Jittering method with 1,000 repetitions (Machado and Santos Silva, 2005). Years are pooled in groups of three; e.g., the coefficient in 1982 is based on the years 1981,1982, and 1983. Estimates are relative to the baseline level in 1997. Difference-in-Differences estimates are reported to the right. These reflect the effect of salt iodization on each GPA quartile. The Difference-in-Differences models are estimated for the period 1990-2006 to avoid bias from the negative trend in the coefficients over time. No control variables are included in the regressions. t-statistics are reported in parentheses. The t-statistics are based on standard misspecification-robust standard errors. Cluster-robust standard errors have not been developed for the Jittering method. If I instead estimate the coefficients using just one repetition and standard quantile regression with cluster-robust standard errors, the estimates and t-statistics are: 0.06 (2.7), 0.05 (2.4), 0.05 (2.6), 0.03 (1.5) from the first to fourth quartile of grades.

Figure A.6: Treatment Effects by Age at Second Reform



Slope of Treatment Effects and Tests of the Mechanisms

Intercept	Slope	Test 1 (slope=0)	Test 2 (intercept=slope)
0.0811	-0.0052	0.0174	0.0000
(0.0190)	(0.0022)		

Note: The figure plots estimates of the effect of salt iodization on the standardized high school GPA of students first affected by iodized salt at the ages 9-18, using the discrete treatment variable. Each point is a separate Difference-in-Differences estimate for students who graduated in the post-reform years 2002-2011. Students who graduated in 2002-2011 were, on average, 18-9 years old when the second salt fortification reform was implemented in 2001. Hence, the coefficient for age 9 (age 18) in the figure is the Difference-in-Differences estimate for students who graduated in 2011 (2002). The table below figure A.6 reports estimates of the slope and intercept of a linear regression going from age 18 to age 9. The intercept is the estimated treatment effect for students first treated at age 18, and the slope is the effect of an additional year of exposure to salt iodization during childhood. Columns 3 and 4 report the p-value of a t-test for whether the slope is different from zero and the p-values of an F-test for whether intercept is equal to the slope. Standard errors are clustered by high school institution. The baseline set of controls is used: Parents: Income percentile, years of schooling, age. Students: Age, birth year, gender, high school institution, number of siblings, birth order.