Ironing Out Deficiencies: Evidence from the United States on the Economic Effects of Iron Deficiency

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Abstract: Iron deficiency reduces productive capacity in adults and impairs cognitive development in children, causing worldwide losses that reach into the billions of dollars. In 1943, the United States government issued War Food Order No. 1, which required the fortification of bread and flour with iron to reduce iron deficiency in the working age population during World War II. This universal fortification of grain products increased per capita consumption of iron by 32 percent. I use the exogenous timing of the federal law and the "Study of Consumer Purchases in the United States 1935-1936" to measure the economic effects of the fortification program. Areas with lower levels of iron consumption prior to the mandate experienced greater increases in wages and school attendance between 1940 and 1950. A long-term follow up suggests adults in 1970 with more exposure to fortification during childhood received higher wages, more years of schooling, and were less likely to live in poverty.

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Section I: Introduction

Micronutrient deficiencies plague the developing world. The World Health Organization estimates that over 4 billion people suffer from iron deficiency, which leads to impaired cognitive development in children and reduced work capacity in adults. Renewed interest in combating micronutrient deficiencies in developing countries stems from the potentially large impact of health interventions on productivity and quality of life. Ranking development policies in terms of cost-effectiveness, the Copenhagen Consensus of 2008 puts iron and iodine fortification as the third most effective intervention (Lomborg, 2009). The loss of productive capacity from direct impairment and reduced human capital investment reaches into the billions of dollars, while it costs only 12 cents per person annually to implement a flour fortification program (Horton and Ross, 2003).

Fortification is not the only strategy to reduce micronutrient deficiencies. An alternative policy is to rely on the secular increase of incomes. For many years the World Bank's view about how to reduce nutritional deficiencies was to implement policies that would increase incomes more generally (World Bank, 1981)[1]. Behrman and Deolalikar (1987) and others, show that the income elasticity of a number of macro- and micronutrients to be very close to zero. Their result implies that rising incomes at the lower end of the distribution, whether through economic development or income redistribution, may not immediately lead to decreases in malnutrition. This leaves open the possibility for governments to intervene to improve the population's health by using fortification programs. As of 2009, 63 countries had already implemented flour fortification programs; however, 72 percent of all flour produced remains unfortified (Horton, Mannar, and Wesley, 2008). As the governments of some developing nations contemplate implementing such programs, a need arises for reliable estimates of both the health benefits of fortification programs and the economic benefits derived from those improvements in health.

Historically, developed nations experienced hunger and malnutrition until the 20th century. The poor nutritional status of European populations is evidenced by their stunted heights (Steckel, 1995). Fogel (1994) argues that agricultural productivity in 18th and 19th century Britain and France could not produce enough calories to allow the population to reach optimum heights. The United States, however, has been blessed with abundant and cheap food supplies for much of its history. A lack of calories did not afflict the population of the U.S., allowing an early

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[1] World Bank (1981), p. 59… "Malnutrition is largely a reflection of poverty: people do not have enough income for food. Given the slow income growth that is likely for the poorest people in the foreseeable future, large numbers will remain malnourished for decades to come…The most effective long-term policies are those that raise the incomes of the poor…"

attainment of modern heights relative to Europe (Steckel, 1995).[2] The U.S. height advantage was not limited to farmers in the countryside. Industrial workers of the United States were relatively taller than in Britain (Logan, 2006).

While not afflicted with serious hunger, the United States did suffer from a lack of micronutrients in the diet. Calories and protein are not the only important parts of a diet. An adequate consumption of vitamins and minerals are necessary for specific bodily processes.[3] The United States population has periodically endured bouts of micronutrient deficiency. A lack of niacin leads to the disease pellagra, which claimed 5,000 lives annually during the 1920s (Park et al., 2000). Rickets, a childhood bone disease caused by a deficiency in vitamin D, caused 400 deaths annually in the 1920s even though the condition was rarely fatal and cod liver oil was a known treatment (Weick, 1967). Rickets was so prevalent that Eliot (1925) showed 34 percent of infants living in New Haven Connecticut developed rickets before their eighth month. Physical examinations for the World War I draft report simple goiter and cretinism, caused by iodine deficiency, in 0.5 percent of all draftees with rates as high as 3 percent from states in the Upper Midwest and Northwest (Love and Davenport, 1920). Iron deficiency and anemia were prevalent as well. During the 1930s and early 1940s, a large number of dietary surveys and case studies that observed levels of iron in the blood serum were conducted throughout the country.[4] The percent of the population considered iron deficient ranged from 47 and 74 percent of white and African-American children in a rural Tennessee county to less than 5 percent in Southern California. One of the major accomplishments of nutritional science and public health in the 20th century is the elimination of these disorders from the U.S. population today through better diets and food fortification (Semba, 2007).

This paper focuses on estimating the economic benefits from the 1943 iron fortification program in the United States. Iron deficiency functionally impacts humans through decreased cognitive development in children and lower work capacity for both children and adults, which implies that the impact may be detectable in economic outcomes. The historical experience of iron fortification in the United States provides a useful quasi-experiment to estimate the potential benefits

[2] Average U.S. heights did decline during urbanization in the 19th century possibly due to increased infectious disease morbidity and a food distribution system that distanced urban dwellers from the fresh foods produced in the countryside.
[3] Iron for energy conversion, iodine and zinc for brain development and function, vitamin D and calcium for bone formation, vitamin A for eye and nerve function.
[4] The results from the diet surveys are aptly summarized in Kruse et al.'s *Inadequate Diets and Nutritional Deficiencies in the United States* (1943).

of this particular type of health intervention. In 1943, the United States government issued War Food Order No. 1, which required the fortification of bread and flour with dietary iron in an effort to increase the work capacity of the population during World War II. The almost universal fortification of grain products was successful in that it increased per capita consumption of iron by 32 percent (Gerrior, Bente and Hiza, 2004). I estimate the effect of the iron fortification program on adult wages, children's school attendance, and on the outcomes of adults exposed to the program during childhood.

The fortification program provides a targeted public health intervention causing plausibly exogenous improvements in health. Public health is likely a normal good with wealthier areas choosing higher health expenditures, making it an endogenous choice at the local level. Correlations between public health expenditures and economic outcomes do not lend themselves to a clear causal interpretation. I follow a strand of the economics literature that examines quasi-experiments in targeted public health interventions (Bleakley, 2007; Feyrer, Politi and Weil, 2008; Cutler et al., 2010). War Food Mandate No. 1 provides a means of identification of the effect of iron that is not confounded by endogeneity with income. I argue that health improvements from reductions in iron deficiency, in the U.S. case, are exogenous to the future growth prospects of areas with low iron intake. Wartime concerns about the productive capacity of the civilian population spurred the federal government to require the addition of thiamine, niacin, and iron to bread and flour in 1943. Transcripts of the public hearings on the proposal clearly indicate the major concern was niacin deficiency and pellagra. The addition of iron was somewhat of an afterthought, which is evidence in favor of exogenous timing. Furthermore, the technology required to cost-effectively fortify flour with micronutrients was not developed until the mid-1930s.

The paper's identification strategy hinges on pre-intervention geographic variation in iron deficiency and the exogenous timing of the intervention. The hypothesis is that places with a higher pre-existing prevalence of iron deficiency experienced larger gains in wages and human capital from fortification. Unfortunately, no national survey was conducted during the 1930s to measure directly the prevalence of deficiency or anemia. Absent this type of health survey data, the best way to measure the prevalence of iron deficiency in the United States is to construct a measure of iron consumption from food diaries. Specifically, I use the "Study of Consumer Purchases in the United States, 1935-1936", which provides a detailed account of all foodstuffs consumed by a household in the previous week. I convert the quantity of each food item consumed in the household into its iron content using the National Nutrition Database (USDA, 2009).

I find that after the iron fortification mandate in 1943, wages and school enrollment in areas with low iron intake increased relative to other areas between 1940 and 1950. Results come from difference-in-difference estimators and a multi-period specification that allows for differential trends in the outcome across areas. Results are robust to the inclusion of demographic characteristics, regional convergence and WWII military spending. One notable concern is that labor markets that were particularly hard hit during the Great Depression rebounded at a faster pace during the 1940s. If these areas were also the areas with low pre-existing iron consumption, the results would be biased. The income and young child school attendance results are robust to this hypothesis, whereas I cannot separate the effects of mean reversion in the labor market from iron effects on the school attendance of high school-aged students. Estimates are consistent with a one standard deviation difference in iron consumption leading to a 1.62 to 2.5 percent relative increase in wages from 1940 to 1950, and a 2.4 percentage point relative increase in school attendance. The impact from iron fortification is economically large accounting for 1/30th and 1/3rd of the gains in real income and school attendance in the low iron consumption areas over the decade. The economic benefits from iron fortification are quite large relative to the costs required to implement the program. In 1943, enrichment cost 5 cents per pound of flour or \$7 per person annually (Wilder and Williams, 1944). The results suggest that annual income increased by \$36 per person, which represents only part of the total benefits of fortification. The national fortification mandate thus had a benefit-cost ratio of at least 5:1, which is within the range for those found in developing countries (Horton and Ross, 2003).

Iron deficiency can have lasting long-term effects on human capital formation and wages. To examine the possible long-term effects, I use the 1970 census microdata to follow up on children that potentially benefitted from the iron fortification mandate by looking at outcomes when they are adults. The cohort analysis provides variation in childhood exposure by combining differences in years of potential exposure based on year of birth, and geographic differences in pre-existing rates of iron deficiency. Older cohorts serve as a comparison group as they received less exposure to fortified bread as a child. Cohorts with more exposure to fortification tended to have higher earnings, more years of schooling, and were less likely to be considered living in poverty by the census. A full 19 years of exposure implies a 9.5 percent increase in earnings as an adult, a 0.13 year increase in years of schooling, and a decrease in the likelihood of living in poverty by 0.23 percentage points.

Section II: Iron Deficiency and the Fortification of Flour and Bread

Section II.a: Health affects of iron deficiency

Iron deficiency is the most common nutritional deficiency worldwide and is caused by low dietary intake, blood loss, growth, pregnancy, and impaired absorption. The main function of iron in the human body is to transport oxygen through the bloodstream and facilitate its use by organs and muscles. Iron deficiency is defined as insufficient iron available in the body's bone marrow to produce red blood cells. About two-thirds of the body's iron is found in hemoglobin, one-seventh found in the bone marrow to produce red blood cells, with small amounts in muscle and scattered throughout the remaining organs of the body.

Iron deficiency and iron deficiency anemia affect the functioning of several organ systems. In infants and children, iron deficiency may cause developmental delays and behavioral disturbances. These disturbances include decreases in motor activity, social interaction, and attention (Beard and Connor 2003). Studies that follow the same children over time have found that iron deficiency can have long-lasting effects on neural and behavioral development of children even if the deficiency is reversed during infancy (Lozoff et al. 2006). Between the ages of 12 and 18, adolescents are at higher risk because of increased iron requirements. The risk subsides by the end of puberty for males, but menstruation keeps the risk high for women throughout the childbearing years. In treatment-control studies on subjects with iron deficiency or anemia, cognitive ability and work capacity in adolescents treated with iron-therapy improved relative to the placebo group (Groner et al., 1986; Sheshadri and Gopaldas, 1989; Seomantri et al., 1985).

Iron deficiency causes reduced work capacity in adults. The mechanism works through a reduced ability to move oxygen throughout the body and a reduction in the tissue cell's ability to process oxygen. The reduction in oxygen manifests itself in reduced aerobic capacity, endurance, energetic efficiency, voluntary activity and work productivity (Hass and Brownlie 2001). Differences in iron status can partially explain differences in work productivity. For example, experiments have shown that Sri Lankan tea pickers are more productive when not suffering from a deficiency of iron (Hass and Brownlee 2001). A lack of iron also affects productivity at work by reducing cognitive ability and skill acquisition.

Daily iron requirements vary significantly by age and sex. The Institute of Medicine has issued recommended daily allowances of vitamins and nutrients since the 1940s. Table 1 lists the most recent update to the recommended daily allowances for iron. Iron balance is a complicated mechanism that depends a wide variety of dietary and bodily factors. The amount of iron in the body is determined by intake, loss, and storage. The body regulates its balance of iron mainly through adjusting the absorption rate from diet. When iron stores are high or sufficient, the body absorbs less of the iron consumed. Conversely, when the balance of iron is low the body can absorb more of what was consumed. The absorption rate is determined by a number of factors: amount of iron in the body, rate of red blood cell production, amount and kind of iron in the diet, and the presence of substances that can inhibit or promote absorption. The absorption rate can range anywhere from 1 percent to more than 50 percent of dietary iron consumed. Iron from meat is more easily absorbed than is iron from plants. The presence of vitamin C in the meal enhances absorption, while polyphenols in vegetables, tannins in tea, and calcium tend to inhibit iron absorption.

Section II.b: Policy options to address micronutrient deficiencies

Policymakers are faced with three possible interventions to reduce micronutrient deficiency: fortification, supplementation, and food-based approaches. Food fortification consists of artificially increasing the amounts of micronutrients in common staple foods. With regular consumption of a fortified food an individual can reduce the risk of deficiency. An important advantage of fortification programs is the ability to reach a large population and play a preventative role. Moreover, a public health authority does not need to single out at-risk individuals for treatment; the entire population that consumes the fortified staple food receives treatment.

To the extent a person needs to change his eating habits in order to achieve the recommended daily allowance through fortified foods, he might not follow the plan. This disadvantage applies to food-based programs as well, in which an individual is given information about the proper nutritional diet in an effort to change their eating habits. For this reason, supplementation has been the preferred choice for therapeutic programs. Supplementation involves giving the patient a dose of the micronutrient, which is relatively simple once the individual to receive treatment is identified. Daily or frequent doses of the supplement are needed in order to prevent deficiency. This requires a stable distribution network without service breaks. The patient must also pay increased attention to the supplement schedule, whereas fortification requires only the frequent consumption of staple foods.

A debate continues on the cost-effectiveness of supplementation vs. food-fortification for a continuing prevention program (Horton and Ross, 2003). Studies of the actual costs of implemented programs have contradictory results dependent on place (Howson et al. 1998, p.6). The effectiveness of a fortification program depends on the centralization and commercialization of the food supply. The more concentrated is production of the staple, the less monitoring and regulation is needed to implement the program. For example, the salt industry in the U.S. during the 1920s was highly concentrated with 36 percent of production by companies in Michigan, 18 percent in New York, and 14 percent in Ohio. In 1924, the Michigan legislature passed legislation requiring iodine be added to all salt for the Michigan market. Production of salt was so concentrated that the producer's found it wise to produce only iodized salt to sell to the entire country (Feyrer, Politi and Weil 2008). Part of the success of flour fortification can be attributed to the high concentration of the flour industry in the

1940s. A small number of commercial flourmills and large regional commercial bakeries made monitoring the mandate relatively easy. Evidence also points to some economies of scale in the fortification process. Large bakeries and flourmills were more likely to adopt fortification voluntarily before the federal mandate.

Section II.c: The federal bread and flour fortification mandate

While acknowledging that the diets of many Americans were deficient in micronutrients, the medical profession and regulatory authorities were originally steadfast in their opposition to the addition of any foreign substances to food products for much of the first half of the 20th century (Wilder and Williams, 1944). The views of the Food and Drug Administration and the American Medical Association changed in the 1930s during the debates over whether to allow vitamin D fortified milk as a tool to prevent rickets. Eventually the FDA acquiesced, but maintained the authority to regulate the labeling of fortified foods. In an important step for nutritionists in favor of fortification, the American Medical Association backed proposals to enrich bread and flour with iron and thiamine in 1939 (Bing, 1939). Moreover, in May 1941 the Food and Drug Administration enacted regulations stipulating the labeling of "enriched" wheat flour and breads. This regulation did not require manufacturers to fortify their products, only that to use the label "enriched flour" the product must contain the following in each pound: between 1.66 and 2.5 milligrams thiamine and between 6 and 24 milligrams each of niacin and iron (Federal Register, 1941). These levels represent a doubling to tripling of the micronutrient content of unenriched products. Two years later the FDA increased the minimums and maximums for enriched flour. The earlier guidelines were sufficient to increase iron, B1 and B6 intake for the average diet. However, experts agreed that more vitamins needed to be added to ensure that individuals at the lower end of the income distribution received adequate amounts of the vitamins and minerals (Federal Register, 1943).

The first federal requirement to fortify flour and bread came in the form of War Food Order No. 1 in 1943, which mandated fortification at the "enriched" levels. The mandate had a large, abrupt, and long lasting impact on iron consumption in the United States. Figure 1 shows the 32 percent increase in per capita iron content of the U.S. food supply in the early 1940s.[5] Between 1937 and 1946 the per capita daily iron content of the U.S. food supply increased 3.1 milligrams, which is 40 percent of the recommended daily allowance for men and 17 percent for women. Before the intervention in 1943, iron in the U.S. food supply was gradually declining as consumers switched

[5] The USDA constructed this series by using the disappearance method -- production plus imports minus farm use and exports (USDA, 2004). The slight decline after 1945 resulted from reductions of the maximum level of iron allowed in enriched bread.

from grains to diets high in sugar and fats (USDA, 2004). The increase in iron consumption during the 1940s can be directly linked to the fortification of flour and bread. In the 1930s, 26 percent of the iron supply came in the form of grains, but after fortification 32 percent came in the form of grains despite the fact that grain consumption continued its decline.

Section III: Data and Descriptive Statistics

My identification strategy hinges on pre-existing differences in the prevalence of iron deficiency. Unfortunately, no national survey was conducted to measure the prevalence of iron deficiency or anemia during the 1930s.[6] Absent this type of health survey data, the best way to measure the prevalence of iron deficiency in the United States is to construct measures of iron consumption using food diaries from the 1930s. Specifically, I use the "Study of Consumer Purchases in the United States, 1935-1936". The Bureau of Labor Statistics, USDA, Works Progress Administration, and the National Resource Committee conducted a massive survey to elicit the earning and purchasing patterns of a sample of households from across the United States. One part of the survey recorded the spending habits of 61,000 households across the United States, providing a detailed account of all foodstuffs consumed by the household in the past week. The survey contains a surprising amount of detail in the food expenditure schedule of the survey: over 681 individual food items, as well as the number of meals provided for each member of the household. The survey included families in 51 cities (population of 8,000 and up), 140 villages (population of 500 to 3,200), and 66 farm counties across 31 states.

The diet of each household is converted into the amount of iron provided using the USDA National Nutrition Database (USDA, 2009).[7] Using the number of meals provided in the home, I calculate the average daily per person iron consumption for each household.[8] A daily measure of iron intake simplifies comparisons to the recommended daily allowances published by the USDA. Summary statistics are reported in table 2.

Substantial variation exists across households in the daily consumption of iron. Figure 2 plots the distribution of household per capita daily consumption of iron in the 1936 sample -- pre-

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[6] The earliest estimates we have on iron deficiency and anemias come during the 1970s with the National Health and Nutrition Examination Surveys conducted by the Public Health Service. WWI and WWII draftee medical examinations did not record iron deficiencies or anemias.

[7] A list of conversions is provided in the Data Appendix. I provide a detailed explanation of how I construct this measure in the Data Appendix.

[8] The food schedule does not ask about meals provided outside the home, such as meals purchased in restaurants or provided by schools. However, the dataset does include the number of meals provided by the household for each member. As long as meals provided outside of the home have a similar average iron intake to meals provided by the household, then my constructed iron consumption measure should be adequate.

intervention. Note that the recommended daily allowance for men of working age is 8 mg and for women is 18 mg. Figure 2 suggests that a large portion of households were not consuming the recommended daily allowance of iron. Around half of all households in the sample are under the 8 mg per day cutoff, with a mean around 8.1 mg. No similar survey was conducted after the iron fortification programs in the 1940s, so I cannot construct a similar figure using the same type of data.

The composition of the iron consumption measure lends itself to examining changes in the distribution after flour and bread were fortified in 1943. I construct a counterfactual iron distribution by assuming families consume the same diets as in the 1936 survey, with the addition that grain products now provide the fortified amount of iron to the diet. Figure 2 also plots the counterfactual. A comparison of the two figures clearly shows that fortification shifted the distribution to the right. The average consumption of iron increases by 3.5 mg from 8.1 mg to 11.6 mg; the number of households in the sample that consume less than 8mg per day declines from 56 percent to 23 percent. The counterfactual shows that the fortification program increased iron consumption at the household level and reached families at the lower left tail of the distribution. Those most in need were not left out of the benefits of the intervention.

To capture geographic variation in the intensity of iron consumption and facilitate merging with census microdata, I average the iron consumption measure over all households within a state economic area (SEA).[9] The required conversions to construct household iron consumption leaves the sample with 3,545 observations across 82 state economic areas in 30 states. Substantial variation exists across state economic areas in average daily consumption of iron. Figure 3 shows the distribution of SEA average iron consumption. In 1936, the mean SEA consumes 8.17 mg of iron per day, with a standard deviation of 1.47 mg. Just over half of the SEAs consume less than 8 mg per day – the recommended daily allowance for working aged males.

To conduct the analysis of long-term effects of iron deficiency, I use variation in state of birth. Figure 4 shows the variation in state average daily iron consumption. Appendix table A.1 reports the mean iron intake by state. North Carolina has the lowest average iron intake with 5.5mg per day, while New Jersey has the highest with 9.68mg per day. Sixteen states are under the RDA for adult males of 8mg per day, and nine states are under 7mg per day. With the exception of Alabama, the Southern states are all under 8mg per day. A few mid-western states – Michigan, Wisconsin, and

[9] The State Economic Area (SEA) is a concept used by the Bureau of the Census. A SEA consists of either a single county or a group of contiguous counties in the same state with similar economic characteristics shortly before the 1950 census when they were first defined. See Donald J. Bogue's "State Economic Areas" (1951) for a full description of the procedure used to group counties. The main analysis of the paper aggregates to the state economic area as this is the smallest geographic unit reported by the microdata samples.

Indiana – are under 8mg per day as well. For the most part, the New England and Mid-Atlantic states have relatively higher levels of iron consumption.

Outcome Data

All individual level outcome data and demographic controls come from the Integrated Public Use Microdata Series (IPUMS, Ruggles et al. 2010) a program that harmonizes decennial census microdata. The basic specification uses census data from 1940 and 1950 as these years bracket the iron fortification program. Income data are limited to 1940 and 1950 as these are the only census years that provide both income and state economic area. Additional data from 1910 through 1950 are used to control for time trends in the school attendance regressions. Table 2 contains summary statistics for outcome variables. Income includes all wage and salary income of each individual from the year prior to the census canvas.[10]

School attendance includes observations between 8 and 17 years of age. The census recorded a child as attending school if the child was enrolled in a "regular school system" at any time over the month of March in 1940, and over the two months of February and March in 1950.

The data suggest areas with low iron consumption pre-intervention have lower incomes and less school enrollment in 1940. Clearly, iron consumption is not distributed randomly across counties. Areas with low iron consumption differ from high consumption areas along a number of dimensions. For instance, low iron consumption areas are more likely located in the South. Therefore, I move on to a regression analysis to control for these factors.

Section IV: Identification Strategy

My identification strategy combines pre-intervention geographic variation in the prevalence of iron deficiency combined with the exogenous timing of the fortification campaign in 1943. The setup provides plausibly exogenous changes in iron status across geographic units. The analysis is essentially a difference-in-difference estimator with a continuous treatment variable. Pre-existing differences in iron deficiency across geographic areas of the country are necessary for identification. Low iron consumption areas stood to benefit more from the iron fortification campaign. Figure 5 supplies evidence that this was the case. The horizontal axis plots the pre-intervention fraction of households in 1936 in an SEA that consume 8 mg or less daily. The vertical axis gives the percentage point decline in deficiency in the counterfactually constructed distribution of post-intervention iron consumption discussed above. A positive slope can be seen from the plotted points. Geographic areas

[10] To be included in the sample, observations need to list their main occupation as wage and salary, have a positive income, not attend school, and be over 17 years old. Top-coded values are multiplied by 1.4. The top-coding cutoffs change from $5,001 in 1940 to $10,000 in 1950.

with a higher intensity of iron deficiency before the intervention experienced larger declines in deficiency after the intervention.[11] Furthermore, the mandate was a success in that it quickly affected the consumption of iron in the United States by 32 percent (Gerrior, Bente and Hiza, 2004).

The second piece of the identification strategy comes from the timing of the federal mandate. Its passage was external to what was going on in the low iron consumption areas. Fortification was mandated at the federal level, removing the scope for states, counties, and individual consumers to select into or out of treatment. Fortification of bread and flour occurred when it did mainly because of the war effort during the 1940s. The U.S. government felt that nutrient deficiencies on the home front would reduce industrial capacity to supply the armed forces. Before the 1940s, fortification using iron, niacin, and thiamine was technologically infeasible. Developments in the 1930s to produce micronutrients synthetically dramatically reduced the costs of a fortification program. By 1944, the cost of adding the three nutrients in the mandate had fallen to .05 cents per pound of flour in 1944$ (author's calculations using data from Wilder and Williams (1944)).

The variable of interest in the following regressions is $(IRON_s \times POST_t)$ – subscript s indicates state economic area and t indicates year. The variable $IRON_s$ denotes the pre-intervention average iron consumption in state economic area *s*. The variable $POST_t$ denotes an indicator equal to one if year t is after the intervention date of 1943. I estimate equation (1) to get the relative difference between the 1940 and 1950 census in outcome Y_{its} associated with pre-existing iron status.

(1) $$Y_{its} = \beta \cdot (IRON_s \times POST_t) + (\tilde{\delta}_r \times t) + \delta_t + \delta_s + X_{its} \cdot \theta + \varepsilon_{its}$$

The unit of observation is the individual by year by SEA level. Year dummies – δ_t – and state economic area fixed effects – δ_s – are included as well, giving a difference-in-difference estimator. In sections V and VI, I assess the contribution of iron fortification to changes in contemporaneous adult wages and children's school attendance. The outcome variable Y_{its} is the natural log of annual wage and salary income in the wage regressions, and a binary indicator for school attendance in the human capital regressions. A vector of individual level controls – X_{its} – includes occupation, industry, four educational attainment categories, an education specific quartic in age, race, veteran status, marital status, number of children, and sex for the wage regressions. Schooling regressions control for age, race, sex, and race and sex interacted with year.

Increases in iron status during the 1940s might be correlated with unobservables that are trending over time or regional convergence in wages and schooling rates during the decade (Wright

[11] The geographic variation comes from many different factors, such local dietary habits, seasonal food supplies, and rural/urban status.

1986). To control for these possible confounding factors region specific time trends are included. Because the census asked about income starting in 1940, the short time series only allows for a two period trend in income. The income regressions include a census region specific time trend – $(\tilde{\delta}_r \times t)$ – to allow for regional convergence in wages during the 1940s. The census allows for a much longer time series for school attendance. I use this additional data to include an SEA specific linear time trend. The advantage of allowing for place specific time trends is that it limits the possibilities for bias from omitted variables. The estimates will be robust to including controls for convergence and trends of unobervables. The main concern becomes potentially unobserved shocks to the outcome variables during the 1940s. I explore potential confounding factors further in the respective sections for each outcome.

Section V: Fortification Effects on Contemporaneous Adults

In this section, I use regression analyses to estimate the changes between 1939 and 1949 in wage and salary income, labor force participation, and hours worked due to increases in iron consumption.[12] Standard errors are clustered at the SEA by year level to allow for a common shock to income at the local level.[13] Base specification results are presented in table 3, where each entry is the coefficient on $(IRON_s \times POST_t)$ from a separate regression. Iron fortification in 1943 reduced iron deficiency more in low intake areas relative to high iron intake areas. Thus we should see larger gains in areas with low iron intake pre-intervention. In the wage regressions, the coefficients give the additional increase in wages from 1939 to 1949 experienced by areas with low relative to high iron consumption.[14]

Column (1) of table 3 reports the results from income regressions. The estimate in row (A) suggests that iron fortification led to higher incomes in 1949 in areas with lower iron consumption. This result is robust to regional convergence in wages during the 1940s (Wright, 1986). Per capita World War II spending does not explain away the effect of iron fortification on wages. Moreover,

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[12] The full sample includes wage and salary workers aged 18 and above with positive income. I exclude observations without educational attainment information or that are recorded as full-time or part-time students. Because the 1940 census only inquired about wage and salary income, I exclude observations that list the main class of worker status as self-employed.

[13] Standard errors are clustered at the SEA by year level according to procedure developed by Liang and Zeger (1986). I am mainly concerned about correlation of unobserved shocks to individuals within the same SEA in the same year. Serial correlation does not pose a serious problem as the time periods in the panel are separated by ten years (Bertrand, Duflo and Mullainathan, 2004). In the full sample, the number of clusters = 164. Results from regressions that aggregate to the SEA level using the procedure developed by Donald and Lang (2007) are consistent with those of the microdata regressions.

[14] The baseline specifications use the SEA average iron consumption per day as the variable of interest. Because low iron consumption areas experience larger relative gains, the coefficient is expected to be negative.

this effect is robust to the possibility that iron consumption might be correlated with local labor markets hard hit in the 1930s that had relatively quick recoveries during the 1940s.[15] While somewhat attenuated from row (A), the coefficient in row (B) is still statistically and economically significant. For the full sample, a one milligram difference in average iron consumption is associated with a 1.08 log point difference in wage and salary income. Increasing SEA average iron consumption by one standard deviation translates into a 1.62 percent relative increase in income between 1939 and 1949. This difference would account for 2 percent of income growth in the low iron areas over the decade.

Important differences appear between demographic groups. Panel (B) of table 3 reports results for males and panel (C) for females. Row (C) estimates equation (1) using the entire sample of men. The effect of iron fortification on men's wages is over double that for the entire population. Subsequent rows slice the male sample even further. The results do not appear to be driven by older men, as the estimate in row (D) shows when limiting the sample to men between the ages of 18 and 60. Moreover, the population effect seems to be driven entirely by younger men. Rows (E) and (F) report estimates for men under 28 and men aged 28 and over, respectively. A one-milligram difference in iron consumption implies a 3.13 percent difference in income for men under the age of 28, whereas for older men it represents a 0.5 percent difference that is imprecisely estimated.

Industry and occupational choice may be affected by a change in iron status. For example, a worker might upgrade to a higher paying occupation or industry because of the change in relative returns induced by iron fortification. Thus industry and occupation may be endogenous to the treatment. I run identical regressions to those above, except controls for occupation and industry are not included. The coefficient estimates are essentially unchanged from before. For the sake of brevity, the results are reported in table A.2 in the appendix. The relative gains in income do not appear to be caused by a differential movement to higher paying occupations and industries by young men in the low iron consumption areas.

While income gains did not come from occupational upgrading, that does not mean that the impact of fortification was not concentrated in certain occupations. Randomized experiments of iron supplementation combined with direct observation of productivity suggest larger improvements in jobs that require more strenuous physical work (Horton, Alderman, and Rivera, 2009). To examine this issue, I divide the sample of men into blue-collar and white-collar occupations and conduct

[15] All income regressions account for regional convergence by including region specific linear time trends. To control for differential mean reversion in labor markets hard hit by the Great Depression, I include SEA specific 1937 unemployment rates interacted with $POST\text{-}1943_t$.

separate regressions.[16] As rows (G) and (H) attest, the iron fortification effect is concentrated in blue-collar workers. The point estimate for white-collar workers is less than half that for blue-collar, and it is imprecisely estimated. The results I find here conform to those found in the medical literature. Jobs that use more physical energy experience bigger gains from improved iron status.[17]

The above regressions clearly point to relative gains in income over the 1940s for young blue-collar workers in low iron consumption areas. The effect of iron fortification potentially works through a number of mechanisms. Part of the increase could be from increases on the intensive or extensive margins of employment. Labor force participation by men is already quite high and has little room for improvement. Thus it is no surprise that changes on the extensive margin of work were not correlated with pre-intervention iron consumption.[18] Conditional on working positive hours, weekly hours showed a small relative increase in low iron consumption areas over the 1940s, to the tune of around one-third of an hour per week. This represents less than one percent of the average weekly hours in 1940, and around 2.3 percent of a standard deviation. The magnitude of the relative increase in hours is not able to explain the full income gains. Furthermore, adding either hours or weeks of work as controls to the income regressions only slightly changes the coefficients of interest. A differential increase in hours worked does not explain the gains in income from iron fortification. The evidence points to the causal channel as an increase in productivity.

No clear conclusions about the effects of iron fortification on women can be made. Medical surveys show that women are much more likely to be iron deficient then men, both in the current United States (Brotanek et al., 2007), and in developing countries (Horton, Alderman, and Rivera, 2009). Presumably, women were more likely than men to be iron deficient during the 1940s as well, suggesting that women should have experienced larger declines in deficiency. If so, one might expect larger effect for women than for men. However, this is not the case. Panel (C) of table 3 reports results for samples of women. The full women's sample has the opposite sign of what is expected and is imprecisely estimated, suggesting no effect on the full sample on average.[19]

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[16] Observations are separated into blue- and white-collar occupations using the IPUMS 1950occ variable. Blue-collar jobs include farmers, farm managers, craftsmen, operatives, service workers, farm laborers, and laborers (occ1950 codes of 100, 120, and between 500 and 970). White-collar jobs are those in the professional and technical, managers, officials, and proprietors, clerical and kindred, and sales workers categories (occ1950 codes below 500, except for 100 and 120).

[17] An alternative explanation for my results is that white-collar workers did not suffer from iron deficiency in the low iron consumption areas, whereas blue-collar workers did.

[18] Results reported in table A.2 of the appendix.

[19] Splitting the sample into married and unmarried women produce coefficients with opposite signs. Future work is needed to examine the mechanism through which iron fortification affected women versus men.

Section VI: Contemporaneous Effects on School Attendance

In this section I use regression analyses to estimate the relative gains in school attendance between 1940 and 1950 due to increases in iron consumption.[20] Iron fortification in 1943 reduced iron deficiency more in low iron areas relative to high iron areas. Thus we expect larger gains in school attendance in those areas where consumption of iron was low before the fortification mandate. Results are presented in table 4, where each entry is the coefficient on $(IRON_s \times POST_t)$ from a separate regression with standard errors clustered at the SEA by year level.[21] The coefficients give the additional increase in school attendance from 1940 to 1950 experienced by areas with low relative to high iron consumption.[22] Regressions control for race, sex, age, and race and sex interacted with $POST_t$, along with year and state economic area indicators.[23]

Row (A) of table 4 reports results without including demographic controls, which suggest that iron fortification increased school attendance over the 1940s in areas with low iron consumption before the mandate. A 1 mg difference in iron consumption implies a 0.94 percentage point difference in school attendance rates. Adding in demographic controls in row (B) does not substantially change the coefficient. The impact of iron fortification on school attendance is economically significant; a one standard deviation increase in iron consumption implies an increase in school attendance of 1.4 percentage points, which represents about one-third of the total school attendance increase in the low iron areas between 1940 and 1950.

One concern is that regional convergence could be confounding the results. During the 1940s, attendance rates in the south converged with those of the non-south.[24] A large number of the low iron state economic areas are located in the South, implying that the variable of interest is potentially correlated with unobserved factors driving the South-Non-South convergence in

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[20] School attendance is measured as a binary indicator equal to one if the child attended school for at least 1 day in the past month for the 1940 census or in the past 2 months for the 1950 census. The full sample is limited to children of ages 8 through 17 living in the state economic areas under consideration.

[21] Standard errors are clustered at the SEA by year level. I am mainly concerned about correlation of unobserved shocks to individuals within the same SEA in the same year. Serial correlation does not pose a serious problem as the time periods in the panel are separated by ten years (Bertrand, Duflo and Mullainathan, 2004). In the full sample, the number of clusters = 164.

[22] The baseline specifications use the SEA average iron consumption per day as the variable of interest. Because low iron consumption areas experience bigger relative gains, the coefficient is expected to be negative.

[23] Differential changes in parental income and education could potentially be correlated with the measure of iron consumption. Collins (2007) illustrates the convergence in income and educational attainment achieved by successive cohorts of southern relative to northern men over this period. Ideally, I would like to include controls for parental education and income. Unfortunately, the sampling procedures followed by the enumerators for the 1950 census called for asking detailed sample-line questions to only a single member of the household. Thus, the school attendance and income variables are never recorded together within the same respondent household.

[24] The gap in age 8-17 school attendance between Non-South and South census regions was 9 percentage points in 1940, and closed to 4.5 percentage points by 1950 (Author's calculations using IPUMS census microdata)

attendance. Three specifications are used to control for regional convergence: census region specific time trends using 1940 and 1950 data, region trends using 1910-1950 data, and SEA specific time trends using 1910-1950 data.

Row (C) presents results using the most conservative control for convergence by including a census region time trend in the regression on 1940 and 1950 census data. I report results for this specification to allow for the possibility of a break in region specific trends during the 1940s. Because only two years of data are used, the trend is equivalent to interacting a region dummy with $POST_t$, which potentially absorbs much of the variation in the variable of interest. Many of the low iron consumption areas are in the South, so regional convergence driven by iron fortification will load onto the trend term and not onto β. The point estimates on β decrease by almost two-thirds for the full sample. Even in this most conservative control for regional convergence we still see an increase in school attendance that is consistent with a positive impact of iron fortification.

The wealth of data contained in the IPUMS allows me to extend the sample to include the 1910 through 1950 censuses.[25] The additional years of data allow me to control for a longer time series of pre-existing trends reducing the scope for convergence driven by iron fortification to load onto $\tilde{\delta}_r$ and away from β. Row (D) reports results from estimating equation (1) on data from 1910-1950 with controls for a census region linear time trend. Results are consistent with those of the basic specification. Row (E) reports results from a similar regression, but with using SEA specific linear time trends to allow for even more detailed pre-existing trends in school attendance. Again, the results are consistent with the basic specification, although slightly larger in magnitude.

In general, changes in school attendance are related to how changes in iron status move children over the margin of whether or not to attend school. The effects of iron fortification do not seem to be concentrated in one single demographic group, although there are some important differences across groups. The theory suggests that groups closer to the margin of school attendance experience larger effects from iron fortification. Columns (2) through (8) of table 4 report the coefficient of interest from regressions using samples of different demographic subgroups. Iron fortification led to bigger magnitude increases in school attendance for the 13-17 year olds, compared to 8-12 year olds. The percentage point increase for the older age group is twice that of the younger group in row (A) and almost seven times in row (E) with SEA time trends included. School attendance of the younger age group was already quite high in 1940 at 96 percent, whereas the older age group attendance was only 82 percent. The older age group was closer to the margin of attending

[25] State economic area is not included as a geographic identifier in later censuses.

school as they had better outside labor market opportunities. Because the attendance of 13-17 year olds might be tied to current labor market opportunities, in column (4) I include controls for place specific differences in the pace of recovery from the lows of the 1930s. I interact the SEA 1937 unemployment rate and per capita war spending with the $POST_t$ variable. Including controls for labor market conditions diminishes the magnitude of the relationship for the older children.

The results from columns (4) through (8) are consistent with iron fortification having larger effects for groups closer to the margin of attending school. The estimated effect for nonwhites is over twice that of whites; however, controlling for SEA time trends reduces the magnitude of the relationship. The rapid convergence of black and white attendance rates in the South before 1940, might attenuate the nonwhite coefficient (Margo, 1990). However, the rate of convergence seems to continue through the 1940s as well. Males experienced larger effects from iron fortification than did females. The coefficient for males is about twice that of females; however once again, including SEA time trends diminishes the difference.

Section VII: Long-Term Effects on Children: Cohort Analysis

Iron deficiency's biggest detrimental effects might be on the cognitive development of infants and toddlers, which the simple binary school attendance measure of the census does not capture. Early childhood incidence of iron deficiency might also extend to long-term effects manifested when these children are adults. To examine these possible long-term effects, I follow up on children that potentially benefitted from the iron fortification mandate by looking at their corresponding adult outcomes using the 1970 census microdata. Economic outcomes I examine include income, educational attainment, and poverty status as an adult. Variation in childhood exposure to the iron fortification campaign comes both across geographic areas based on differences in pre-intervention iron consumption, and across cohorts within an area. Older cohorts serve as a comparison group as they received less exposure to fortified bread as a child.

This type of cohort analysis poses a problem in how each observation as an adult is linked to the corresponding exposure to the fortification program as a child. Each adult needs to be linked to the geographic area where they resided as a child. Because of migration, the use of 1970 state of residence introduces unnecessarily large error into the exposure variable. For this reason, I use the state of birth as the geographic unit in calculating exposure to fortification.

The cross-cohort comparison I use is the number of years as a child exposed to the iron fortification campaign interacted with the pre-fortification average iron consumption in state *s* – (EXP_{ik} x $IRON_s$). Childhood years are defined as time under the age of 19, as most children will have finished their educational choices by this age. The mandate came into force in 1943, thus adults born in 1924 and before received no exposure, with EXP_{ik} increasing linearly until equal to 19 for cohorts born in 1943 and after. I estimate the following regression model:

$$Y_{isk} = \beta \cdot (EXP_{ik} \times IRON_s) + \delta_s + \delta_k + X_{isk} \cdot \theta + \varepsilon_{isk} \quad (3)$$

State of birth and cohort fixed effects are included in the regression. Demographic controls include binary indicators for $age \times nonwhite \times female$ cell, state of birth interacted with nonwhite, female, and $nonwhite \times female$.

Table 5 presents the results from the estimation of equation (3). Children born later and in states with lower iron consumption pre-intervention had more years of exposure to the fortification campaign. Children with more exposure to fortification were more likely to have higher earnings, more years of schooling, and were less likely to be considered living in poverty than children with less exposure. A full 19 years of exposure at a one standard deviation difference in iron consumption implies a 9.5 percent increase in earnings as an adult, a 0.13 year increase in years of schooling, and a decrease in the likelihood of living in poverty by 0.23 percentage points.

Older cohorts might have been hit by a temporary shock that caused lower productivity and lower iron consumption. Even without an effect of iron status on wages, younger cohorts would experience income gains because of reversion to the mean once the temporary shock dissipated. I attempt to control for this possibility by including the 1940 log of state average wage and salary income interacted with age cohort.[26] Some evidence of mean reversion exists for all three outcomes, but all β's remain statistically and economically significant. The coefficients from the income and poverty status remain around or above two-thirds their values when mean-reversion is not controlled for. The coefficient on years of schooling drops to below half that previously found. Possible mean reversion does not explain all of the effects of the iron fortification program.

Panel B of table 6 reports the results using samples of different demographic subgroups. There seem to be some difference in the effect of iron fortification between the groups. In general, males experience more of an effect than females (except for poverty status), and nonwhites more than whites. However, the white and nonwhite coefficients from the income regressions are not significantly different from each other.

Section VIII: Discussion

Many developing countries in recent years have considered or already implemented micronutrient fortification programs based on the high estimated benefit-cost ratios of fortification.

[26] From author's calculations using the 1940 census microdata provided by IPUMS.

The history of fortification in developed countries provides a useful quasi-experiment to estimate the economic benefits of iron fortification. This study contributes to the literature on the effects of micronutrients, and health more generally, on economic activity by looking specifically at the iron fortification mandate of 1943 in the United States. This episode in food policy provides a number of advantages. First, enough time has passed since the mandate to allow an examination of the long-term consequences. Second, useful comparison groups can be constructed based on pre-existing geographic differences in iron deficiency.

Areas that consumed high amounts of iron pre-intervention did not stand to gain as much from fortification. Levels of iron deficiency were likely already low; any additional iron would thus have a small effect on. I find that areas with lower consumption of dietary iron before the federal government mandate experienced greater gains in income and school attendance. These results are robust to the inclusion of demographic controls, regional convergence, and differential speeds of recovery from the lows of the Great Depression. Gains in wages are concentrated in younger blue-collar males, with results consistent with a hypothesis that the causal mechanism works through an increased wage rate. Adjustments on the extensive and intensive margins do not explain much of gains in wages. To more fully examine these cumulative and long-term effects, I analyze the adult outcomes of children exposed to the bread fortification program. The evidence suggests that cohorts with more exposure were more likely to experience increased earnings, higher educational attainment, and a lower probability of living in poverty.

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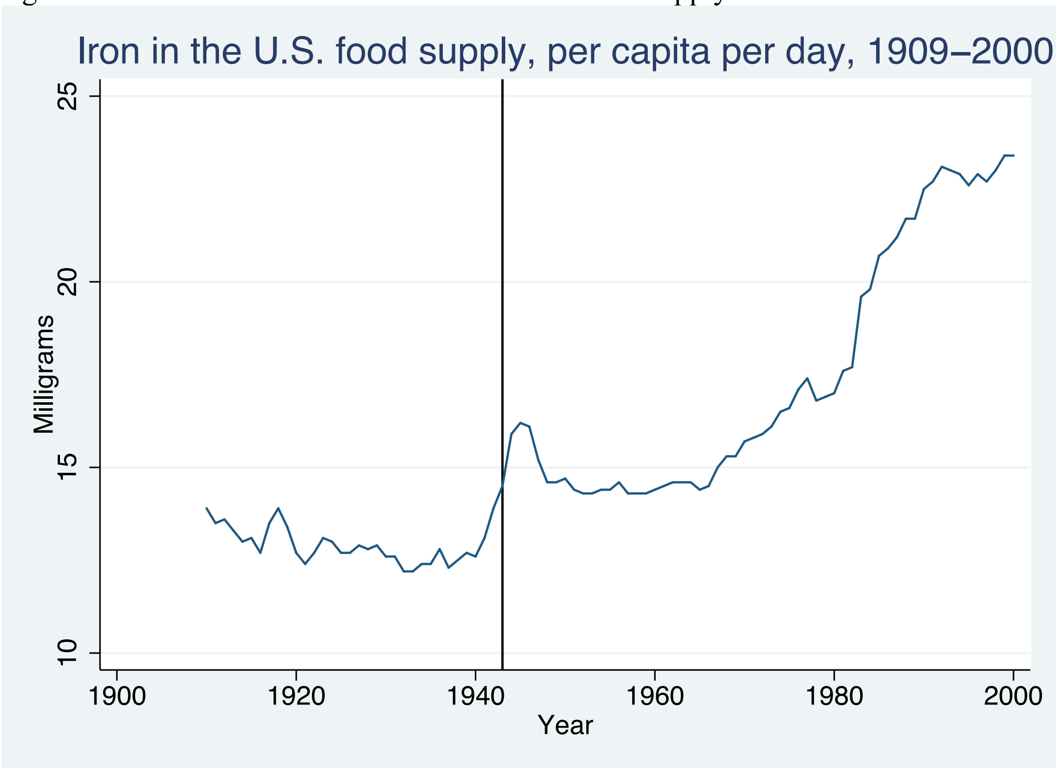
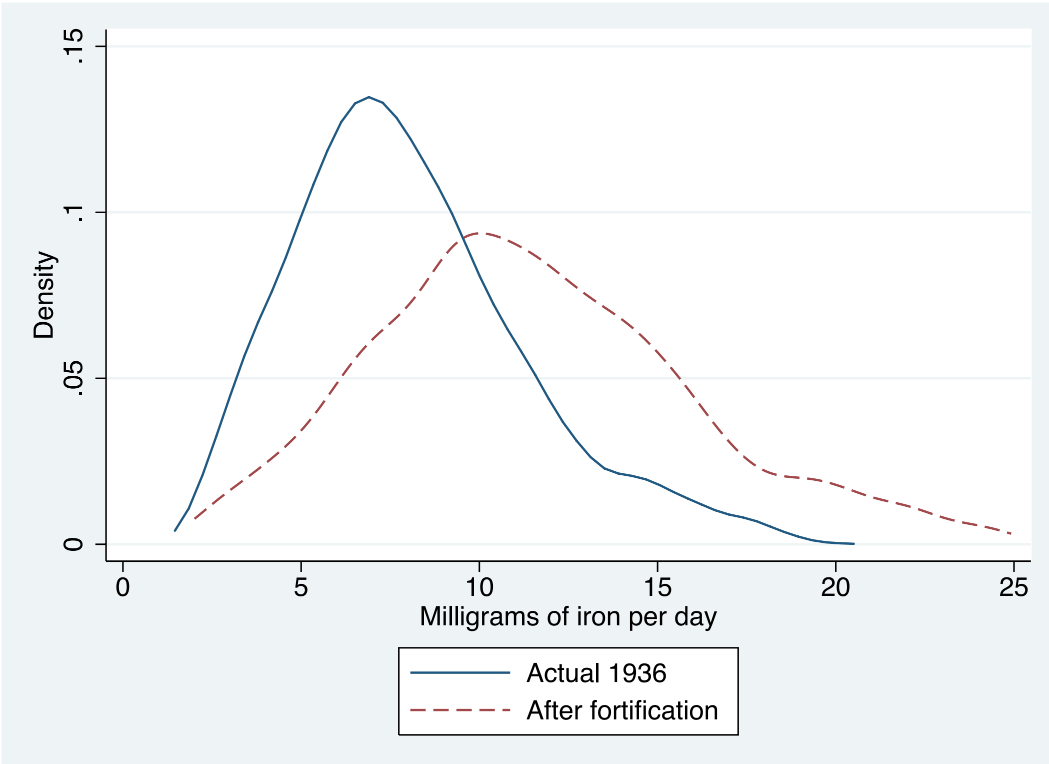
Figure 1. Historical iron levels in United States food supply.



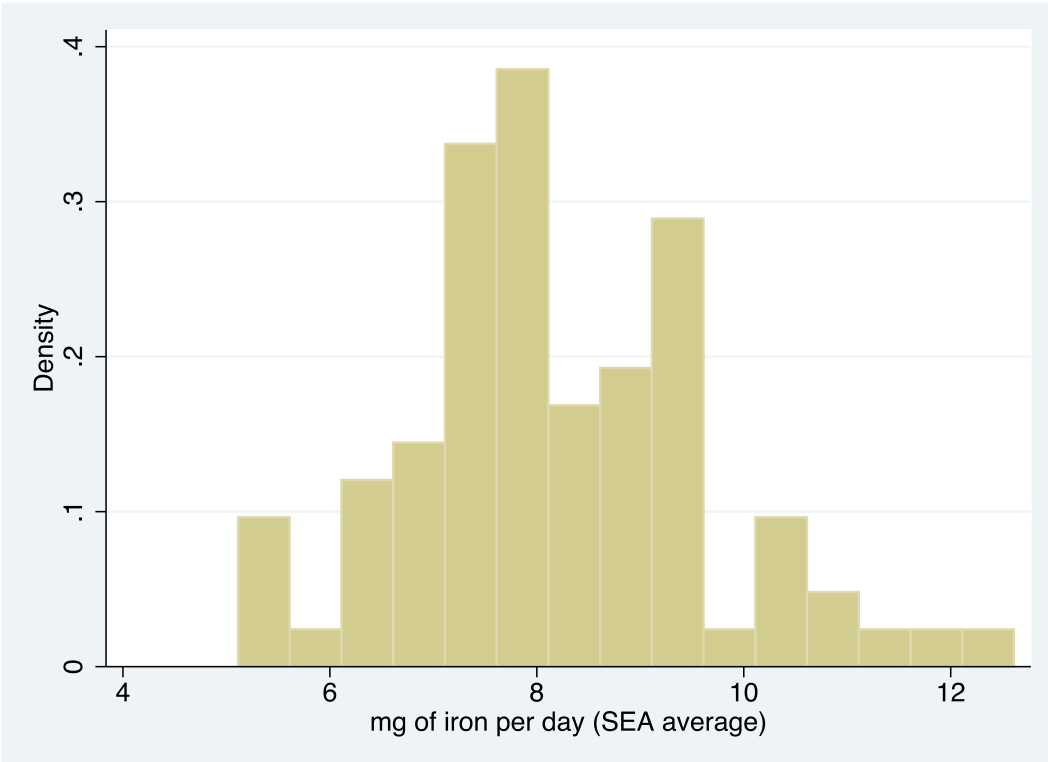
SOURCE: USDA (2004)

Figure 2: Frequency of household iron consumption in 1936, and counterfactual distribution after with iron fortification



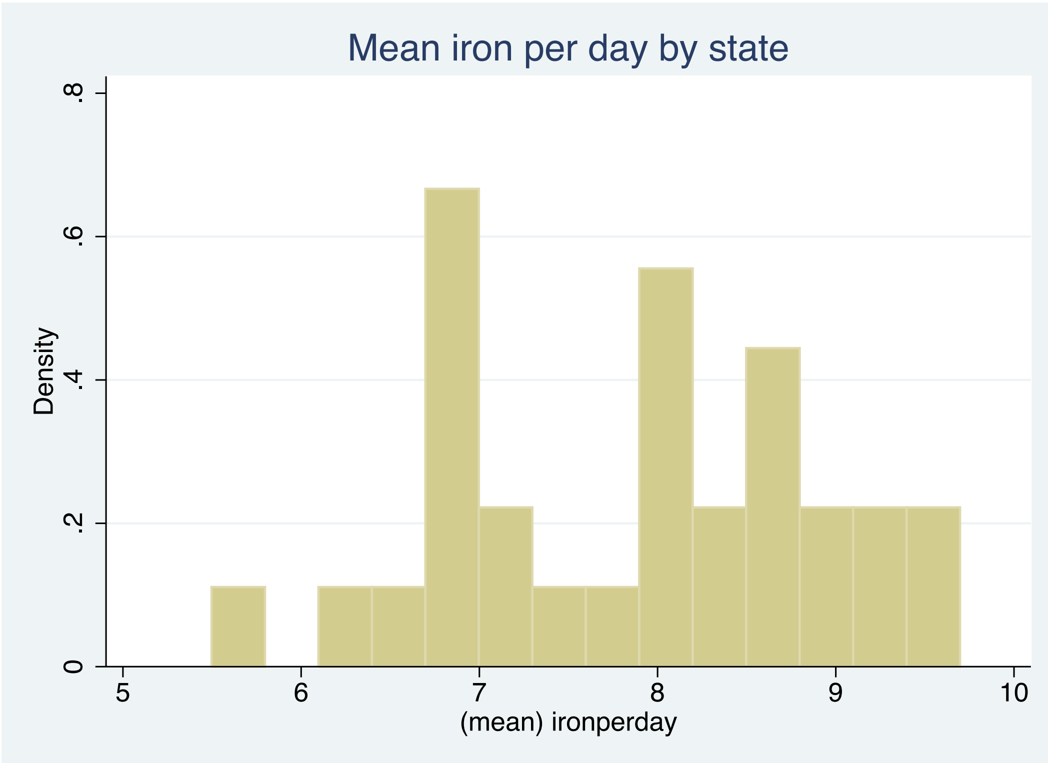
SOURCE: Author's calculations using "Study of Consumer Purchases, 1935-1936" and USDA (2009).

Figure 3: Frequency of SEA mean per day iron consumption in 1936.



SOURCE: Author's calculations using "Study of Consumer Purchases, 1935-1936" and USDA (2009).

Figure 4: Frequency of state mean daily iron consumption in 1936.



SOURCE: Author's calculations using "Study of Consumer Purchases, 1935-1936" and USDA (2009).

Figure 5: SEAs with higher deficiency rates in 1936 experienced bigger reductions in deficiency post-fortification in the counterfactual.

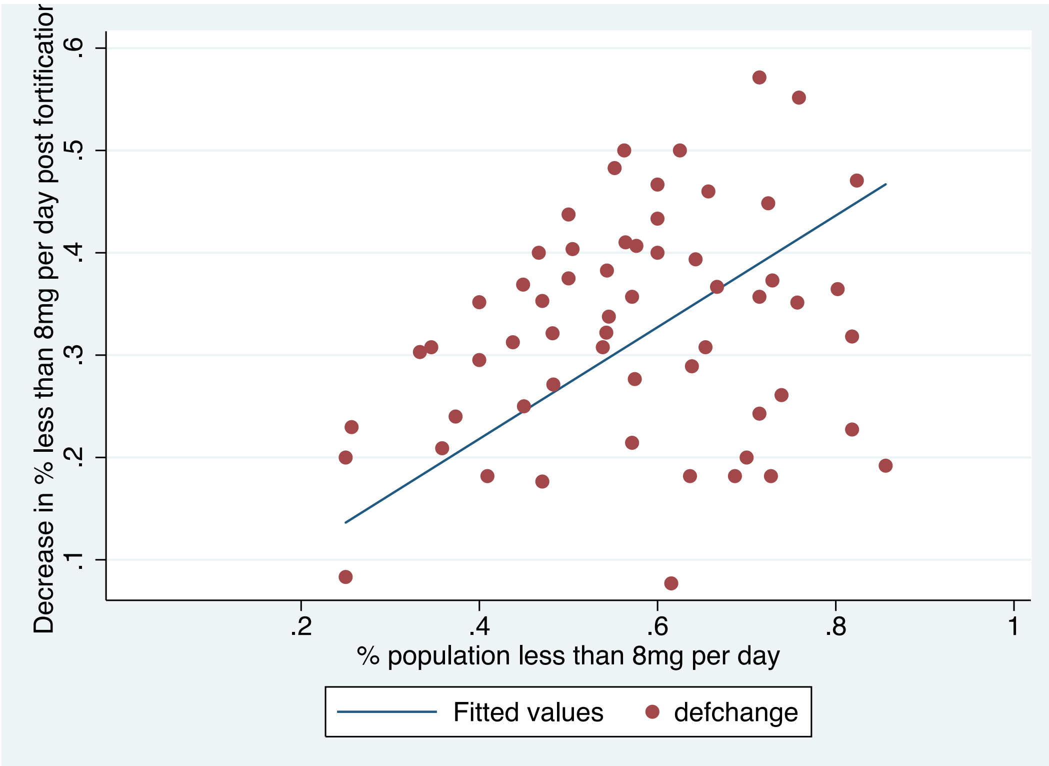


Table 1. Recommended Dietary Allowances for Iron in mg per day

Age	**Males**	**Females**	**Pregnancy**	**Lactation**
7 to 12 months	11	11	N.A.	N.A.
1 to 3 years	7	7	N.A.	N.A.
4 to 8 years	10	10	N.A.	N.A.
9 to 13 years	8	8	N.A.	N.A.
14 to 18 years	11	15	27	9
19 to 50 years	8	18	27	9
51+ years	8	8	N.A.	N.A.

Source: Institute of Medicine (2001)

Table 2: Summary Statistics

Household level		Whole Sample	Iron Consumption <8mg	Iron Consumption > 8mg
Iron Consumption in mg	mean	8.1		
	median	7.5		
	st. dev.	(4.1)		
Observations		3,545		
SEA level				
Iron Consumption in mg		8.2	7.1	9.3
		(1.5)	(0.77)	(1.0)
Iron Consumption in mg after fortification		11.6	10.1	13.1
		(2.2)	(1.5)	(1.7)
Households under 8 mg		0.54	0.66	0.40
		(0.21)	(0.12)	(0.19)
Households under 8 mg after fortification		0.23	0.35	0.11
		(0.19)	(0.18)	(0.08)
Observations*		82	41	41
Income variables				
Income in 1940		904	815	993
		(203)	(213)	(150)
Income in 1950 (in 1940$)		1,522	1,416	1,629
		(259)	(274)	(194)
Men's income in 1940		1,005	917	1,095
		(232)	(245)	(180)
Women's income in 1940		605	539	671
		(146)	(139)	(123)
School Enrollment Variables				
School Enrollment in 1940		0.888	0.874	0.903
		(0.045)	(0.054)	(0.028)
School Enrollment in 1950		0.919	0.913	0.924
		(0.037)	(0.043)	(0.030)
Male school enrollment in 1940		0.886	0.866	0.905
		(0.054)	(0.065)	(0.029)
Female school enrollment in 1940		0.891	0.882	0.900
		(0.042)	(0.048)	(0.033)
White school enrollment in 1940		0.895	0.886	0.903
		(0.037)	(0.043)	(0.027)
Nonwhite school enrollment in 1940		0.867	0.821	0.913
		(0.167)	(0.205)	(0.105)
School enrollment of 8-12 year olds in 194(		0.957	0.0951	0.962
		(0.027)	(0.034)	(0.016)
School enrollment of 13-17 year olds		0.823	0.799	0.847
		(.071)	(0.082)	(0.048)

NOTES: Means are over SEA averages of variables with standard deviations displayed below in parentheses. All wage and schooling data comes from the IPUMS. See Data Appendix for construction of iron variables. Wage data includes all observations with postive income, wage & salary employment as first occupation, and over 17 years old. Topcoded values of income are multiplied by 1.4. Schooling variables include children between the ages of 8 and 17 unless otherwise noted. *Nonwhite specific averages are basedon a lower number observations as some SEAs do not have any individual level nonwhite observations in the IPUMS sample. Black specific variables are based on the following number of SEAs: nonwhite income - 73, diff in nonwhite income - 65, nonwhite schooling attendance - 71, diff in nonwhite school attendance - 60. Observations for nonwhite specific variables are evenly split between HI and LO iron consumption SEAs.

Table 3: Base results for Contemporaneous Adults

	(1)	(2)	(3)
Dependent variable	Log Wage and Salary Income	Conditional Hours	Conditional Weeks
	Panel A: Full Sample		
Controls for 1937 Unemployment			
(A) No	-0.0169***		
	(0.00388)		
(B) Yes	-0.0108**		
	(0.00484)		
Panel B: Men (all including controls for 1937 unemployment)			
(C) *All Men*	-0.0268***	-0.288*	0.0847
	(0.00458)	(0.147)	(0.0696)
(D) Ages under 60	-0.0149**		
	(0.00643)		
(E) Ages 18-27	-0.0313**	-0.282*	0.0491
	(0.0145)	(0.159)	(0.161)
(F) Ages 28-48	-0.00462	-0.322*	0.0695
	(0.00630)	(0.184)	(0.0550)
(G) Blue Collar	-0.0195***	-0.187	0.0657
	(0.00664)	(0.149)	(0.0841)
(I) White Collar	-0.00821	-0.392**	0.143
	(0.00813)	(0.166)	(0.0913)
Panel C: Women (all including controls for 1937 unemployment)			
(J) All Women	0.00964	-0.0411	0.352*
	(0.00731)	(0.196)	(0.197)
Demo. Controls	Yes	Yes	Yes
Industry and Occupation Controls	Yes	No	No
Region Time Trends	Yes	No	No

Notes: *** p<0.01, ** p<0.05, * p<0.1. Each entry is the coefficient of interest ($IRON_s$ x POST-1943_t) from a separate regression with robust standard errors clustered at the (state x year) level reported in parentheses. Full sample includes all individuals aged between 18 and 65 who are not full-time or part-time students. Income regressions exclude primary job self-employed workers and those with non-positive wage and salary income. Hours and weeks regressions include all workers with positive hours or weeks. Demographic controls include sex, veteran status, marital status, race, educational attainment (< HS, HS, SC, C), and (for wage regressions) an educational category specific quartic in age. Female specific regressions include the number of own children in the household. All regressions control for SEA specific WWII contract spending interacted with POST-1943. Reversion from the labor market lows of the 1930s is controlled for by including the 1937 unemployment interacted with POST-1943.

Source: All individual level data comes from the 1940 and 1950 census microdata provided by IPUMS. SEA specific 1937 unemployment rates, and WWII contract spending comes from Haines (2004). Average iron consumption by SEA is calculated by the author from the "Study of Consumer Purchases, 1935-1936."

Table 4: Effect of Iron Deficiency on School Attendance

Dependent Variable: School attendance binary indicator	(1) Ages 8-17	(2) Ages 8-12	(3) Ages 13-17	(4) Ages 13-17	(5) White	(6) Nonwhite	(7) Male	(8) Female
Years 1940-1950								
Row (A) Eq (1) without region time trend or demographic controls	-0.00940***							
	(0.00191)							
Row (B) Eq (1) without region time trend	-0.00932***	-0.00571***	-0.0107***	-0.00345	-0.00781***	-0.0186***	-0.0123***	-0.00624***
	(0.00180)	(0.00160)	(0.00253)	(0.00257)	(0.00173)	(0.00381)	(0.00192)	(0.00224)
Row (C) Eq (1) with census region linear time trend	-0.00372*	-0.000361	-0.00572*	-0.00322	-0.00395*	0.00506	-0.00538**	-0.00209
	(0.00203)	(0.00178)	(0.00335)	(0.00333)	(0.00206)	(0.0109)	(0.00235)	(0.00308)
Years 1910-1950								
Row (D) Eq (1) with census region linear time trend	-0.0117***	-0.00374**	-0.0176***	-0.0135*	-0.0101***	-0.0173***	-0.0136***	-0.00950**
	(0.00321)	(0.00185)	(0.00551)	(0.00746)	(0.00318)	(0.00602)	(0.00322)	(0.00376)
Row (E) Eq (1) with SEA specific linear time trends	-0.0157***	-0.00361**	-0.0243***	-0.00599	-0.0142***	-0.0168***	-0.0188***	-0.0124***
	(0.00227)	(0.00164)	(0.00383)	(0.00408)	(0.00244)	(0.00373)	(0.00246)	(0.00288)
Controls for labor market reversion	NO	NO	NO	YES	NO	NO	NO	NO

Notes: *** $p<0.01$, ** $p<0.05$, * $p<0.1$. Each entry is the coefficient of interest ($IRON_s$ x POST-1943_t) from a separate regression with robust standard errors clustered at the (state x year) level reported in parentheses. Full sample includes all individuals aged between 8 and 17. Demographic controls include sex, race, age, with sex and race interacted with POST-1943_t. All regressions include year and state economic area fixed effects. Parental income and education is not available from the 1950 census to use as a control. The controls for labor market reversion are the SEA specific 1937 unemployment rate and per capita World War II spending, both interacted with POST-1943_t.

Source: All individual level data comes from the 1910 through 1950 censuses, microdata provided by IPUMS. SEA specific 1937 unemployment rates, and WWII contract spending comes from Haines (2004). Average iron consumption by SEA is calculated by the author from the "Study of Consumer Purchases, 1935-1936."

Table 5: Long-term follow up of children exposed to iron fortification program

	(1)	(2)	(3)	(4)	(5)	(6)
Controls for mean reversion:	No	Yes	No	Yes	No	Yes
Dependent variables:	Log total income, 1969		Years of schooling, 1970		Poverty status, 1970	
Years of exposure X average iron consumption	-0.00261***	-0.00163***	-0.00527*	-0.00211***	0.000446***	0.000337***
	(0.000698)	(0.000189)	(0.00299)	(0.000459)	(0.000122)	(5.56e-05)
Subsamples						
Males	-0.00384***	-0.00216***	-0.00842***	-0.00339***	0.000377***	0.000325***
	(0.000712)	(0.000203)	(0.00283)	(0.000708)	(0.000103)	(7.49e-05)
Females	-0.00219**	-0.00103***	-0.00364	-0.00121**	0.000531***	0.000359***
	(0.000994)	(0.000343)	(0.00355)	(0.000602)	(0.000150)	(8.22e-05)
Whites	-0.00228***	-0.00235***	-0.00286	-0.00359***	0.000378***	0.000499***
	(0.000700)	(0.000199)	(0.00296)	(0.000484)	(0.000130)	(5.60e-05)
Nonwhites	-0.00312***	-0.000932	-0.0180***	-0.00415***	0.00107***	0.0004929
	(0.000899)	(0.000600)	(0.00393)	(0.00150)	(0.000209)	(.0002534)

Notes: *** p<0.01, ** p<0.05, * p<0.1. Robust standard errors clustered on state of birth are reported in parentheses. Each entry is the coefficient from a separate regression of equation (3). Demographic controls include indicators for interatctions of state of birth with nonwhite and female, and nonwhite x female. Indicators for each age x nonwhite x female cell are included as well. State-average iron consumption is matched to individuals based on their state of birth. Mean reversion is controlled for by the interaction of 1940 log state mean total income with age cohort. The full sample consists of all males and females of all races between the ages of 22 and 65 and born in one of the states with iron consumption information.

Source: All individual level data comes from the 1970 census microdata provided by IPUMS. Average iron consumption by SEA is calculated by the author from the "Study of Consumer Purchases, 1935-1936." Log state mean total income from author's calculations using 1940 census microdata provided by IPUMS.

Data Appendix

Data on iron consumption comes from the "Study of Consumer Purchases, 1935-1936." The Bureau of Labor Statistics, USDA, Works Progress Administration, and the National Resource Committee conducted this massive survey in an effort to elicit the earning and purchasing patterns of a national sample of households during the Great Depression. The expenditure schedule recorded the spending habits of 61,000 households across the United States. The food schedule provides a detailed account of the diet of each household by recording their consumption of over 600 individual food items over period of a week. The full sample included 61,000 households, of which 6100 were digitized by the ICPSR.[27] Of this sample, 3.545 observations have the information required to construct the iron measures.

The committee chose to include communities of varying sizes across all regions of the United States. In total, the survey included families in 51 cities, 140 villages, and 66 farm counties across 31 states. The country was split into six regions, with interviews conducted in each region of one large city (252,000 - 302,000), two or three middle-sized cities (30,000-72,000) and four to nine small cities (8,000-19,000). In addition, Chicago and New York were included to cover metropolitan areas of more than 1,000,000 in population. Families from two or more groups of villages (500-3,200) were surveyed from each region, as well as two or more groups of farm counties.

The survey was conducted in three waves. The first wave consisted of a sample of 700,000 families from all the geographic regions of the survey. The number of families selected from each geographic area was in line with the proportion of national population that the geographic area made up. The first wave collected limited information and was used to screen families for the following waves. The second wave surveyed a sample of 300,000 families that include at least two members, married for at least one year, and with no more than ten boarders. Not all race categories were included in the sample in all locations. Non-white households were surveyed only in New York, Columbus, OH, and the South region. Every other geographic area included in the sample only white families. This second wave includes questions on family composition, demographics, income levels and sources, occupation, direct relief, and housing characteristics.

A third wave of 61,000 families was asked to complete a more detailed schedule of income, expenditures -- and important for my purposes -- food consumption. The third wave restricted the population to be included in the sample. In order to be in the third wave, non-farm families had to have at least one wage earner in a clerical, professional, or business occupation. Furthermore, a minimum income of $500 per year for the largest cities, and $250 for smaller areas was required to be included. There were no upper limits on income. Families that received "direct relief" were excluded from the third wave sample. Farm families were required to be full-time farmers.

The food expenditure schedule asked respondents to list the food items consumed by the household in the past seven days. Questions included the type of item, the quantity consumed, the total cost of the item, and whether it was produced in the home or received as a gift. The list included 681 individual food items, as well as write in blanks, for categories including meats of all types, seafood, dairy products, vegetables, fruits, grains, sweets, tea, and coffee. Canned foods are also included. An copy of the food schedule is included below. ICPSR digitized a subsample of the 61,000 families who completed the food expenditure schedule. There are 6134 cases in ICPSR

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[27] The remaining undigitized records remain at the National Archives in Maryland. The digitized data set can be downloaded from www.icpsr.org.

sample with 3,100 coming from urban families and 3,034 coming from rural families. Of this sample, 3200 observations have the information required to construct the iron measures.

Each food item is converted into the iron it provides using the USDA National Nutrition Database (USDA, 2009). Summing across all food items gives the total amount of iron consumed by the household in the previous week. The survey includes the number of meals provided by the household, with which I can calculate the per meal and daily average consumption of iron per person. A daily measure of iron intake simplifies comparisons to the recommended daily allowances published by the USDA. The food schedule does not ask about meals provided outside the home, such as meals purchased in restaurants or provided by schools. However, the dataset does include the number of meals provided by the household for each member. This allows me to calculate iron intake on a per meal basis. As long as meals provided outside of the home have a similar average iron intake to meals provided by the household, then my constructed iron consumption measure should be adequate.

Table A.1: Ranking of average iron consumption by state

State	Average Iron Consumption in mg per day	Ranking	State	Average Iron Consumption in mg per day	Ranking
New Jersey	9.68	1	Maine	7.94	16
Oregon	9.67	2	Connecticut	7.92	17
New York	9.39	3	Pennsylvania	7.82	18
California	9.21	4	Iowa	7.47	19
Colorado	9.01	5	Vermont	7.18	20
Washington	8.97	6	Indiana	7.07	21
South Dakota	8.72	7	Utah	6.99	22
Nebraska	8.68	8	South Carolina	6.98	23
Ohio	8.59	9	Mississippi	6.94	24
Missouri	8.53	10	North Dakota	6.90	25
Montana	8.27	11	Wisconsin	6.87	26
Alabama	8.23	12	Michigan	6.74	27
Rhode Island	8.14	13	Georgia	6.55	28
Illinois	8.13	14	Kansas	6.23	29
Massachusetts	7.97	15	North Carolina	5.50	30

Source: Author's calculations using "Study of Consumer Purchases, 1935-1936."

Appendix Table A.2: Additional results for Contemporaneous Adults

	(1)	(2)	(3)	(4)	(5)
	Base	No Education Controls	No Occ or Ind Controls		
Dependent variable	Log Wage and Salary Income	Log Wage and Salary Income	Log Wage and Salary Income	Labor Force Participation	Occ Score
Panel A: Men (all including controls for 1937 unemployment)					
(A) *All Men*	-0.0268***	-0.0167***	-0.0151*	-0.00265	0.0966
	(0.00458)	(0.00577)	(0.00770)	(0.00203)	(0.0784)
(B) Under 28	-0.0313**	-0.0372***	-0.0313**	-0.00447	0.125
	(0.0145)	(0.0122)	(0.0144)	(0.00572)	(0.130)
(C) Over 27	-0.00827	-0.00824	-0.00833	-0.000771	0.101
	(0.00566)	(0.00566)	(0.00745)	(0.00154)	(0.0821)
(D) Blue Collar	-0.0195***	-0.0194***	-0.0186**	-7.78e-05	0.0694
	(0.00664)	(0.00663)	(0.00834)	(0.000551)	(0.0894)
(E) White Collar	-0.00821	-0.00833	-0.00807	-0.00548*	0.157
	(0.00813)	(0.00811)	(0.0104)	(0.00314)	(0.103)
Panel B: Females (all including controls for 1937 unemployment)					
(F) All Women	0.00964	0.00558	0.00419	-0.00123	0.0157
	(0.00731)	(0.00749)	(0.00747)	(0.00211)	(0.0563)
Demo. Controls	Yes	Yes	Yes	Yes	Yes
Industry and Occupation Controls	Yes	Yes	No	No	No
Region Time Trends	Yes	Yes	Yes	No	Yes

Notes: *** p<0.01, ** p<0.05, * p<0.1. Each entry is the coefficient of interest ($IRON_s$ x POST-1943_t) from a separate regression with robust standard errors clustered at the (state x year) level reported in parentheses. Full sample includes all individuals aged between 18 and 65 who are not full-time or part-time students. Income regressions exclude primary job self-employed workers and those with non-positive wage and salary income. Hours and weeks regressions include all workers with positive hours or weeks. Demographic controls include sex, marital status, race, educational attainment (< HS, HS, SC, C), and (for wage regressions) an educational category specific quartic in age. Female specific regressions include the number of own children in the household. All regressions control for SEA specific WWII contract spending interacted with POST-1943. Reversion from the labor market lows of the 1930s is controlled for by including the 1937 unemployment interacted with POST-1943. Labor force participation is a binary indicator equal to 1 if the respondent is working or seeking work. Occscore is assigns each occupation an income score based on the income distribution in 1950.

Source: All individual level data comes from the 1940 and 1950 census microdata provided by IPUMS. SEA specific 1937 unemployment rates, and WWII contract spending comes from Haines (2004). Average iron consumption by SEA is calculated by the author from the "Study of Consumer Purchases, 1935-1936."