Element of Survival: Isolating the causal effect of access to iodized salt on child health in India

Shubha Lakshmi Bhat, Harvard College (Class of 2009)
Economics and Health Policy Senior Thesis

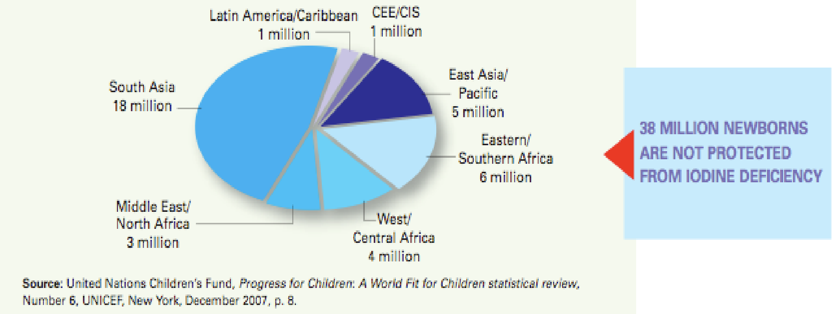
Abstract: Despite India's longstanding efforts to combat Iodine Deficiency Disorders through a Universal Salt Iodization program, only 51% of households were using iodized salt in 2005. In order to justify efforts to actively expand the program, it is crucial to establish a causal link between access to iodized salt and child health. This study examined household salt iodine concentration, anthropometric outcomes, and birth histories of over 18,000 children from the 1998 India National Family Health Survey. To isolate causality, two-stage least squares (2SLS) regressions were used with state-fixed-effects. Innovative district-level instruments were constructed using Geographic Information Systems to predict salt iodine concentration in households and targeting efforts of the government. The 2SLS estimate revealed that increasing the iodine level in salt led to a 1.168 standard deviation increase in height-for-age ($p<0.05$), a 15.9% decreased likelihood of having below-average birth weight ($p<0.05$), a 18.6% increased likelihood of having above-average birth weight ($p<0.05$), and a 2.8% increase in child survival ($p<0.10$).

Introduction: Iodine deficiency disorders (IDD) are one of the most common causes of preventable mental retardation (X. Y. Cao et al., 1994). A meta-analysis of 18 studies of 2214 subjects comparing the performance of iodine-deficient children with that of iodine-sufficient peers on a standardized intelligence tests, concluded that iodine deficiency lowered the mean intelligence quotient by 13.5 points, which indicates a staggering public health problem (Bleichrodt and Born 1994). This shortcoming affects a child's ability to learn, and later in life, to earn. In this way, the negative effects iodine deficiency on both mental and physical health can significantly impede worker productivity and the economy at large. Clearly, eliminating iodine deficiency can have a significant impact on the world's poor.

To combat IDD, the WHO and UNICEF recommended in 1994 the use of iodized salt as a safe, cost-effective and sustainable strategy to ensure sufficient intake of iodine by all individuals. However, despite pushing a Universal Salt Iodization program, progress has been limited. In India, which is a major salt-producing country, only 51% of households were using iodized salt in 2005. This is a particular problem since out of 38 million newborns in developing countries every year that remain unprotected from the lifelong consequences of IDD-related brain damage, a large percentage live in South Asia, as shown in Figure 1 (UNICEF 2008).

However, to justify efforts that the Indian government is making to improve the system, it is important to understand what effect the lack of iodized salt coverage has had on public health. Specifically, it is necessary to determine whether IDD affects not only mental capacities of the nation's children, but also physical capacities. Thus, identifying the causal link between iodine deficiency and child survival and growth will more effectively direct the appropriate resources toward its correction. In doing so, this study also aims to contribute to the methodological literature on measuring intervention impacts.

Figure 1: Children Unprotected from IDD (2000-2006)



Source: United Nations Children's Fund, *Progress for Children: A World Fit for Children statistical review*, Number 6, UNICEF, New York, December 2007, p. 8.

Methodology:

Datasets:

The primary dataset used in this study was from India's second National Family and Health Survey (NFHS-2), which was conducted from 1998-1999 by the International Institute for Population Sciences (IIPS) in Mumbai (IIPS and Macro 2000).[1] This dataset was ideal for two reasons. First, it captured key socioeconomic, cultural, and health information about over 91,8809 households, 90,303 women and 33,132 children in India. Second, it provided district-level identifiers for each household, which was not available in the most recent 2005 NFHS-3 because of privacy issues. This was crucial because it allowed for the use of within-state variation by district in order to estimate causality, which is particularly helpful for assisting policymakers in planning and implementing strategies for improving population health and nutrition programs.

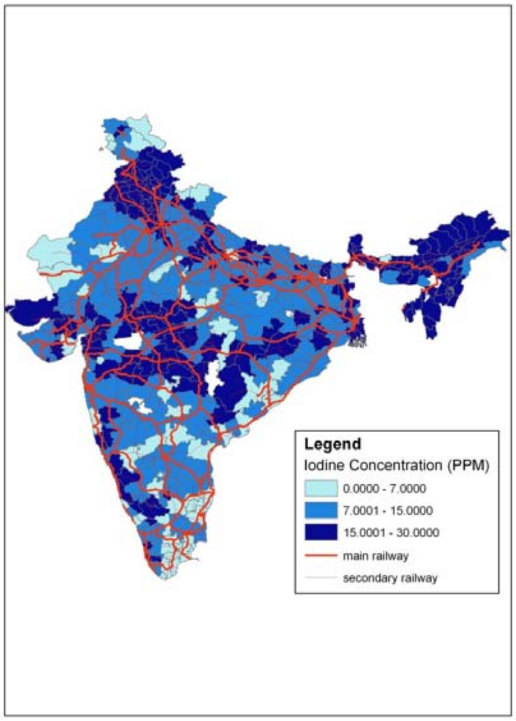
Six secondary datasets were superimposed on a map of India and linked to the NFHS-2 through district-level household identifiers to create a series of district-level control and instrumental variables. Measurements were made using the ArcGIS9 (ArcMap Version 9.3) software. First, MLInfoMap: 1991 Census provided map data on district borders, area and population. Second, the Global Precipitation and Climatology Center's Full Data Re-analysis Project provided information on average annual rainfall for each district. Third, the Shuttle Radar Topography Mission provided 90-meter by 90-meter raster images of elevation. Fourth, the Global Self-consistent, Hierarchical, High-resolution Shoreline (GSHHS) Database Version 1.3 provided information on distances to the closest coast. Fifth, Collins Bartholomew World Premium 2007 provided information about the main and secondary railway lines, as well as the road networks in India. Sixth, the Government of India Salt Department's 2005-2005 Annual Report provided information on how much salt was transported to each state by railroad, road or sea.

Variables:

The explanatory variable of interest in this paper was the iodine level of the salt used in a household. In NFHS-2, interviewers measured the iodine content of cooking salt in each interviewed household using a rapid-test kit and recorded the iodine level as 7, 15, or 30 parts per million (ppm) (IIPS and Macro 2000).

Overall, half of households used cooking salt that was iodized at the recommended level of 15 ppm or more one-quarter of households used salt that was not iodized at all, and 21 percent used salt that was inadequately iodized (less than 15 ppm). The use of iodized salt varied dramatically from one state to another (as shown in Figure 2). The variations could be due to a number of factors, including the scale of salt production, transportation requirements, enforcement efforts, pricing structure, and storage patterns. In particular, salt iodization was likely to be more common in states where salt was transported exclusively by railways, partly because the Salt Department monitored the iodine content of salt shipped by railways.

Figure 2: Iodine concentration



---

[1] At the national level, the overall sample weight for each household or woman is the product of the design weight for each state (after adjustment for non-response) and the state weight. I use these sample weights in my main results.

The five child health outcomes that this paper examined were height-for-age, weight-for-height, likelihood of being born small, likelihood of being born large, and overall child survival. These outcomes were based on NFHS-2 anthropometric data of 18,521 children ages 0-5 years, and NFHS-2 birth history of 21,388 children of all ages.

The first two outcomes, children's height-for-age and weight-for-height were evaluated relative to the median height-for-age and weight-for-height of the 1997 U.S. National Center for Health Statistics (NCHS) reference population, recommended by the World Health Organization. Measures greater than two standard deviations below the reference median considered stunted (height-for-age) or wasted (weight-for-height). Stunting is a sign of chronic, long-term under-nutrition, whereas wasting is a sign of acute, short-term under-nutrition. It was therefore hypothesized that access to household iodine would lead to improved height-for-weight outcomes and have no effect on weight-for-height outcomes. Such a result would support the fetal origins of disease hypothesis.

On average, children in India were borderline stunted at 1.91 standard deviations below the reference population. Those children living in households with salt iodine content of 0, 7, 15 and 30ppm were 2.06, 2.07, 1.98 and 1.67 standard deviations below the median, respectively. Thus, there is a clear corresponding trend between iodine concentration and height-for-age outcome. On the other hand, though children were on average, 0.78 standard deviations below the reference median, they were not low enough to be considered wasted. However, unlike the prediction, there seemed to be a similar rising trend of weight-for-height (0.96, 0.89, 0.75 and 0.6 standard deviations below the reference), which corresponded with rising iodine concentrations (0, 7, 15, and 30ppm, respectively). Such a pattern possibly indicates that there are other factors such as standard of living that may be driving these similar trends.

The third and fourth outcomes, likelihood of being born small and large, were chosen because small newborns generally face substantially higher risks of dying than do newborns of normal or large size. The average birth weight of the small, average and large children was 2.2 kg, 2.8 kg and 3.4 kg, respectively. According to mothers' estimates, 25 percent were small, 60 percent were average, and 14 percent were large. As the salt iodine concentration went up, there was also a corresponding decrease in fraction of children born small and increase in fraction of children born large.

The fifth and final health outcome examined was childhood survival, which was calculated as the fraction of children still living over the total number of children ever born to each woman. In total, the child survival rate was 91 percent. In this case, when broken down by iodine concentration, there seemed to be no difference in child survival rates within households that had 0, 7 or 15ppm. However having 30ppm iodized salt corresponded with a 93 percent survival rate.

Estimation Strategy:

To test whether trends in health outcomes are driven by iodine concentration and not other factors ordinary least squares (OLS) and two-stage least squares (2SLS) regressions were conducted. Below, the empirical specification for the OLS regressions run in this analysis is presented:

$$\mathrm{Y} = \alpha + \beta_1(I) + \beta_2(M) + \beta_3(H) + \beta_4(D) + \beta_5(S) + \varepsilon \qquad (1)$$

In equation 1, Y is the child health outcome of interest. This includes height-for-age standard deviations from the international mean, weight-for-height standard deviations from the international mean, child's size at birth, and child survival. The α is the constant, β_1 is the coefficient for I, the explanatory variable. Iodine levels of 1, 2, 3 and 4 correspond with iodine concentrations of 0, 7, 15 and 30 parts per million, respectively. β_2 is the vector coefficient for M, the mother-level controls. These include characteristics such as age, education level, possession of a health card, body-mass-index, and health status (smoking habits, alcohol consumption, tobacco use, TB, jaundice, asthma, and malaria). β_3 is the vector coefficient for H, the household-level controls. These include characteristics such as the standard of living index, urban environment, and religion of household head. β_4 is the vector coefficient for D, the district-level controls. These include district population density and area. β_5 is the vector coefficient for S, the state-fixed effects. Finally, ε is the error term.

The disadvantage with OLS is that there are several unobservable characteristics that cannot be controlled for which may affect both the outcome and explanatory variable. Although OLS helps identify patterns, it is difficult to use an OLS estimation to determine causality. Therefore, a two-stage least squares (2SLS) methodology is used. The 2SLS technique employs instrumental variables, which are supposed to be highly correlated with the outcome variable *only* through a correlation with the explanatory variable. Below, the empirical specification for the 2SLS regressions run in this analysis is presented:

First Stage $$\hat{I} = \alpha + \beta_1(Z) + \beta_2(M) + \beta_3(H) + \beta_4(D) + \beta_5(S) + \varepsilon \qquad (2)$$

Second Stage: $$Y = \alpha + \beta_1(\hat{I}) + \beta_2(M) + \beta_3(H) + \beta_4(D) + \beta_5(S) + \varepsilon \qquad (3)$$

Equation 2 corresponds with the first stage of the 2SLS estimate. $\hat{I}$ is the predicted value of household salt iodine. Unlike equation 1, β_1 in equation 2 is the vector coefficient for Z, the instruments. These include both institutional and geographic instruments. The institutional instruments include distance to any railroad (Figure 3), distance to the nearest main railroad, fraction of salt transported to the state by railroad, and total road length in the district (Figure 4), which predict access to iodized salt. The geographic instruments include average district precipitation (Figure 5), elevation (Figure 6), and distance to the nearest coastline (Figure 7), which predict baseline endemic iodine deficiency.

Figure 3: Railroad

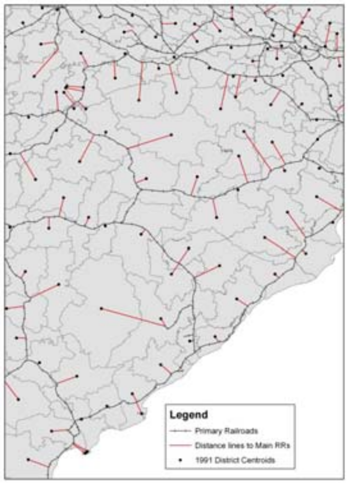


Figure 4: Road length

Figure 5: Precipitation

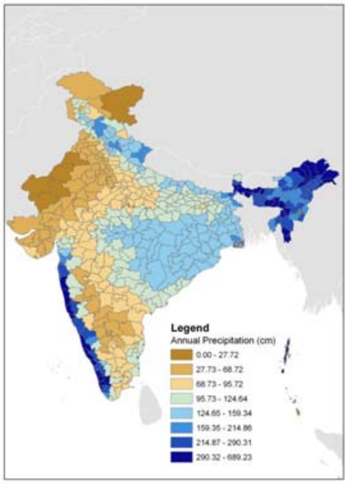


Figure 6: Elevation

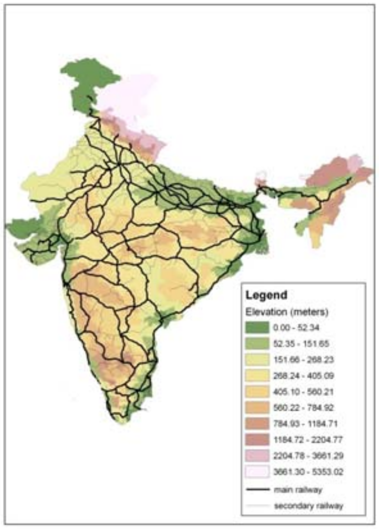
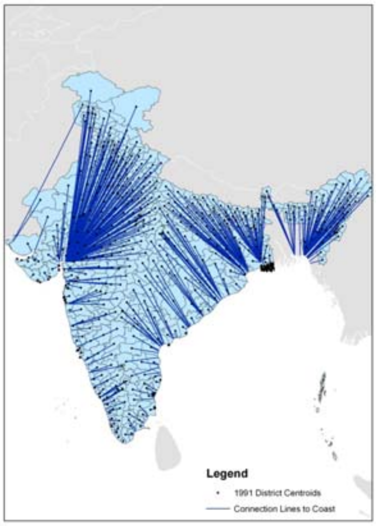


Figure 7: Coast



Equation 3 corresponds with the second stage of the 2SLS estimate. Here, Y is the child health outcome of interest. β_1 is the coefficient for $\hat{I}$, the iodine level predicted by the instruments. As before, the remaining coefficients correspond with mother-, household-, district- and state-level controls.

The 2SLS regressions were also broken down to capture heterogeneous treatment effects on male versus female children and on urban versus rural households to determine whether the effect of iodized salt had a greater impact on certain groups. Finally, three robustness checks were carried out to assess how sensitive the results were to the econometric specification.

Results:

Effect of Iodine Concentration on Child Health Outcomes

	Height-for-age		**Weight-for-Height**		**Small Child**		**Large Child**		**Child survival**	
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	OLS	2SLS	OLS	2SLS	OLS	2SLS	OLS	2SLS	OLS	2SLS
Iodine	0.0375***	1.168***	0.0265**	-0.0341	-0.00798**	-0.159***	0.00222	0.186***	0.00167*	0.0281*
	(0.0131)	(0.311)	(0.0107)	(0.190)	(0.00314)	(0.0556)	(0.00250)	(0.0517)	(0.000999)	(0.0163)
n	20328	18521	20328	18521	23441	21388	23441	21388	23450	21396

Controls *= State fixed effects, population density, district area, standard of living, urban, hindu, muslim, christian, mother's characteristics (age, education, has health card, bmi, smoking habits, alcohol and tobacco use, jaundice, malaria, TB, asthma)*

Instruments *= distance to railroad, distance to main railroad, %salt transported to state by railroad, total road length, annual precipitation, elevation, distance to coast (F = 153.22)*

All regressions are run with sample weights

$* p < 0.10$, $** p < 0.05$, $***=p < 0.01$; Robust standard errors in parentheses

When district-, household-, and mother-level observable characteristics were controlled for in the OLS regression (Colum 1, Table 5), it was found that increasing the iodine concentration by one level (i.e. 0 to 7ppm, 7 to 15ppm, or 15 to 30ppm) correlated with a 0.0375 standard deviation increase in height for age ($p<0.01$). The 2SLS estimate (Column 2, Table 5) revealed that increasing iodine concentration by one level led to a 1.168 standard deviation increase in height for age. Looked at another way, increasing the salt iodization concentration by two levels, from 0 to 15ppm (the concentration recommended by the WHO) led to a 2.336 standard deviation increase in height for age. Essentially, such an effect would put children in India (who on average are at 1.91 standard deviations below the median) at just over normal, on the scale of international growth standards.

Contrary to the prediction, in the OLS estimate (Column 3, Table 5), an increased iodine level correlated with a 0.0265 standard deviation increase in weight-for-height outcomes for children ($p<0{,}05$). However, as expected, the significance of this estimate became nil in the 2SLS (Column 4, Table 5).

Increasing the iodine concentration by one level led to a statistically significant ($p<0.05$) but small (0.008 percent) decrease in the likelihood of being born small in the OLS estimate (Column 5, Table 5). This value became much larger and more significant in the 2SLS. As shown in Column 6, Table 5, increasing iodine concentration level led to a 16 percent drop in the likelihood of being born small ($p<0.01$). The correlation between iodine concentration level and likelihood of being born large was insignificant in the OLS regression (Column 7, Table 5). However, iodine concentration seemed to have a large and significant effect in the 2SLS (Column 8, Table 5). An increase in iodine level led to an 18.6% increase in likelihood of being born large ($p<0.01$).

The OLS and 2SLS estimates (Tables 9 and 9, Table 5) showed that an increase in salt iodine concentration level led to a 0.22 percent and a 2.8 percent increase in child survival rates, respectively ($p<0.1$).

When the sample was broken down by gender and place of residence, there were significantly greater effects of iodized salt on female children and rural households.

Discussion:

The goal of this study was to establish a causal link between access to iodized salt and child health outcomes. Showing the direct relation between iodine deficiency and child survival and growth would help motivate researchers and policy-makers to identify the barriers that prevent India from reaching more widespread use of iodized salt. In addition, illuminating the differential effects of access to iodized salt on subpopulations would help direct resources more appropriately.

This economic analysis is unique because it utilized Geographic Information Systems to measure precise distance and geographic information and connected this information with the district codes of households in this sample. Used together as instruments, the GIS data served to identify causal effects where a controlled experiment was not possible. In addition, because the analysis used the 1998 NFHS, it covered a representative sample of the Indian population as a whole. The timing of the survey captured the effect of five years of universal salt iodization program in India and might have captured the ban on non-iodized salt that had been instated in 1998.

The results of this study suggest that access to iodized salt positively impacted children's height-for-age outcomes, especially for children living in rural settings. The magnitude of the effect is significant since increasing iodine concentration from 0 to 15 ppm seemed to drive the average height-for-age standard deviation from -1.91 (borderline stunted) to nearly +0.43 standard deviations above the NCHS standard. Such an effect can have a significant effect on the future productivity of the nations' children. However, iodized salt might not be the answer to the problem of childhood wasting. This is not a huge concern since the average weight-for-height was not close to 2 standard deviations below the NCSH standard, which defines someone as wasted. In addition, the results suggest that use of iodized salt by mothers might reduce the likelihood of being born small and increase the likelihood of being born large, especially for girls and children born in rural areas. Finally, there seemed to be a positive effect of iodine on child survival, especially for males.

It is important to note that only two of the five outcomes—height-for-age and likelihood of being born large—passed the greatest number of robustness checks. This indicates that we can only begin to extend the fetal origins of disease hypothesis to these two outcomes. However, since even these two outcomes failed to pass the most stringent robustness check, conclusions can only be made with some degree of caution.

There are several measurement issues that this analysis faces. In this sample of the NFHS-2, the reference population used in calculating anthropometric outcomes was the 1997 U.S. National Center for Health Statistics (NCHS) standard. More recently however, a new international reference population was released by the WHO in April 2006 and accepted by the Government of India, which may better assess children regardless of ethnicity, socioeconomic status and type of feeding. In addition, the set of child health outcome variables focusing on size of the newborn are especially prone to selection and reporting biases, since mothers tend to self-report their children as being bigger than they actually are, since size is a measure of health. Finally, the way that I calculated child survival was simply the number of children living over the total number of children born. It is unclear whether such a measurement can really capture the intricacies of child mortality early in life.

For the explanatory variables, an assumption was made that if a household had iodized salt at the time of the survey, it probably has had access to that level of iodized salt throughout the universal salt iodization program, which became more active starting in 1992. However, this assumption may not necessarily hold. The practices of households in 1998 do not necessarily have to reflect the practices of the household five years before.

The instruments used in this analysis showed high relevance in the first-stage regression, yielding high F-stats and significant correlations with the explanatory variable. However, the exogeneity requirement was less convincing. Though precipitation and elevation seem to be less of a problem, distance to the coast and distance to railroads were arguably endogenous. Presumably the closer a household is to a railroad or ocean, the more resources the household can access and therefore the higher standard of living it may experience.

The robustness check limiting the set of instruments to only distance to railroad revealed insignificant results, showing that the main findings might be sensitive to the instruments chosen. Moreover this dataset was limited to district level data. Therefore, it is possible that the instrument used in the most stringent specification did not have enough variation to predict access to iodized salt accurately. Having exact coordinates of households would enable a more robust analysis.

Conclusion:

This paper revealed that an increase in salt iodine levels led to positive and statistically significant child health outcomes—namely, a 1.168 standard deviation increase in height-for-age, a 15 percent decreased likelihood of being small at birth, a 19 percent increased likelihood of being large at birth, and a 2 percent increase in child survival. The paper also provided evidence that access to iodized salt had stronger effects on female children and on children living in rural settings. Therefore, targeting certain populations could potentially have a more powerful impact on child health. This study is innovative in that it utilized unique instruments constructed through GIS data to predict access to iodized salt and isolate its causal effects on childhood health. Using this estimation strategy, the paper shows that the Indian government would do well to continue promoting access to iodized salt in order to secure the health and well-being of its children.

References:

Allen, L. and S. Gillespie (2001). What Works? A review of efficacy and effectiveness of nutrition interventions, UN (ACC/SN).

Bleichrodt, N. and M. Born (1994). A Meta analysis of research on iodine and its relationship to cognitive development. The damaged brain of iodine deficiency. J. Stanbury. New York, Cognizant Communication: 195-200

Cobra, C., Muhilal, et al. (1997). "Infant survival is improved by oral iodine supplementation." J Nutr 127(4): 574-8.

Dunn, J. T. and F. Delange (2001). "Damaged reproduction: the most important consequence of iodine deficiency." J Clin Endocrinol Metab 86(6): 2360-3.

Field, E., O. Robles, et al. (2007). The Cognitive Link Between Geography and Development: Iodine Deficiency and Schooling Attainment in Tanzania. NBER Working Paper Series. Cambridge, MA, National Bureau of Economic Research: 64.

Garrow, J. S., A. Ralph, et al. (2000). Human Nutrition and Dietetics. New York, Elsevier Health Sciences.

Hetzel, B. S. (1989). The Story of Iodine Deficiency; An International Challenge in Nutrition. Oxford, Oxford University Press.

IIPS and O. Macro (2000). National Family Health Survey (NFHS-2), 1998-1999: India. Mumbai, IIPS.

Kapil, U., R. S. Raghuvanshi, et al. (1999). "Utility of spot testing kit in the assessment of iodine content of salt--A mutlicentric study." Indian Pediatrics 37: 182-186.

Lamberg, B. A. (1991). "Endemic goitre--iodine deficiency disorders." Ann Med 23(4): 367-72.

Pelletier, D. L. (1994). "The potentiating effects of malnutrition on child mortality: epidemiologic evidence and policy implications." Nutr Rev 52(12): 409-15.

Pharoah, P. and K. Connolly (1994). Iodine Deficiency in Papua, New Guinea. The damaged brain of iodine deficiency. S. Stanbury. New York, Cognizant Communication: 299-305

Sarkar, S., B. Mohanty, et al. (2007). "Iodine deficiency in school going children of Pondicherry." Indian J Pediatr 74(8): 731-4.

Thilly, C., R. Lagasse, et al. (1980). Impaired fetal and postnatal development and high perinatal death-rate in a severe iodine deficient area. Thyroid research VIII. J. Stockigt, S. Nagataki, E. Meldrum, J. Barlow and P. Harding. Canberra, Austrailian Academy of Science: 20-23.

UNICEF (2008). "Sustainable Elimination of Iodine Deficiency: Progress since the 1990 World Summit for Children." 52.

Whitney, E. N., C. B. Cataldo, et al. (2002). Understanding Normal and Clinical Nutrition. Australia, Canada Wadsworth Group, Thomson Learning.

WHO, UNICEF, et al. (1999). Progress towards the elimination of iodine deficinecy disorders (IDD). Geneva, WHO.

Acknowledgements:

I would like to thank the following people for their tremendous support throughout this research process. Without their help and encouragement this original work would not have been possible.

- **Erica Field**, Assistant Professor of Economics, Harvard University, for being a wonderful thesis advisor and continually guiding me in the right direction.
- **Winnie Fung**, PhD candidate in Economics, Harvard University, for being my thesis tutorial leader and helping me clarify my questions and methodology .
- **Konstantin Styrin**, PhD candidate in Economics and STATA Teaching Fellow, Harvard University, for answering my countless STATA coding questions.
- **Sebastian Linnemyer**, PhD candidate in Economics and Teaching Fellow, Harvard University, for his advice in the Ec980 Junior Tutorial, "Development, Education, and Health."
- **Scott Walker**, Digital Cartography Specialist, Harvard Map Collection, for spending so much time teaching me about GIS, providing me with data and helping me construct map images.
- **Bonnie Burns**, GIS Specialist, Harvard Map Collection, for helping me identify the 1991 India Census Data.
- **Fred Arnold** and **Bridgette James**, DHS/NFHS Archives, for providing me with district coding for the NFHS data.
- **Joan Curhan**, **Debbie Whitney**, **Suzanne Scudder**, for supporting me in the Certificate in Health Policy Program.
- **The Cordeiro Family**, for providing me with a generous grant to travel to India to continue on-the-ground research in July 2008.
- **Darpana Academy of Performing Arts**, for giving me the opportunity during my fall 2007 semester in India, to travel to Valsad (pictured above), a rural district in Gujarat, and become involved in a UNICEF development project that inspired this thesis.
- **Dr. Chandrakant S. Pandav** and **Dr. Arijith Chakrabarty**, International Council for Control of Iodine Deficiency Disorders (ICCIDD), All India Institute of Medical Sciences, New Delhi, for spending time sharing their insight with me on the most recent accomplishments and challenges of the Universal Salt Iodization Program in India
- **Dr.Rajan Sankar**, Regional Manager for the South Asia branch of Global Alliance for Improved Nutrition, New Delhi, for providing me with extensive literature on the history of iodine deficiency.
- **Mr. S. Sunderesan**, Salt Commissioner, and **Mr. M.A. Ansari**, Deputy Salt Commissioner at the Ministry of Salt in Jaipur, Rajasthan, for communicating with me via email regarding questions about the transportation and production of salt throughout the country.
- **Tracy Li, Peter Ganong, Chethan Bachireddy, Prithvi Shankar**, and all my friends and classmates for editing, giving me STATA and formatting tips, and helping make this process enjoyable.
- **My parents**, for their unconditional love.