Effect of Early Life Exposure to the Green Revolution on Aging Outcomes: Evidence from the Largest Aging Data

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Preliminary Draft December 1, 2023

Abstract

The Green Revolution (GR) is the most significant shock to agricultural productivity gains that increased agriculture yields, decreased food prices, increased calorie intake, and reduced infant mortality and poverty. However, its long-term impacts on health are not well understood. This paper contributes to the literature in two different ways. First, we examine how early life exposure to the GR affects later life physical and mental health using the largest aging data.We find a heterogeneous treatment effect suggesting that exposure to the GR around the birth years significantly improved the later life cognitive function among the socially disadvantaged groups and people born in rural areas. Specifically, we find that one standard deviation increase in GR during early life improved these groups' later-life cognitive function between 0.08 to 0.13 standard deviation. We, however, do not find evidence that early life exposure to the GR affects later life physical health using the total number of chronic conditions. Secondly, we contribute by exploring the potential pathways through which GR can affect later-life cognitive function. The significant improvement in schooling among these groups explains some of the positive effects on general cognitive health. We rule

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out that the school construction was driving any positive gain in schooling and also rule out that improvement in height is driving the benefits in cognitive function. Estimates from this paper are vital for policy, as many developing countries are yet to adopt GR, and they will face a more significant aging population in the coming years than the global average.

1 Introduction

The Green Revolution (GR) is arguably the single most significant shock to agricultural productivity gains in developing countries and one of the most significant technological innovations of the 20th century (Gollin *et al.*, 2021). The GR started with the development of the high-yield crop variants (HYV) in the 1960s, which dramatically increased the yield of major crops, mainly wheat and rice.[1] Due to its success, it was adopted worldwide to produce more food for a growing population throughout the developing world. A significant body of research suggests that the Green Revolution technologies contributed to a substantial increase in crop production, food security, GDP per capita, and a decline in food prices, poverty, fertility, and child mortality across different parts of the developing world (Foster and Rosenzweig, 1996, Evenson and Gollin, 2003, Goltz *et al.*, 2020, Bharadwaj *et al.*, 2020, Gollin *et al.*, 2021, Carter *et al.*, 2021). On the other hand, studies also suggest that the Green Revolution had adverse effects of increased infant mortality due to exposure to agrochemicals use (Brainerd and Menon, 2014) and an increase in mid-life chronic conditions (Sekhri and Shastry, 2020). A growing literature documents the link between early childhood conditions and long-term outcomes (Barker, 1990, Almond, 2006, Almond and Currie, 2011, Hoynes *et al.*, 2016, Aizer *et al.*, 2016). With more availability of food (nutrition) and higher family income due to the GR, one may expect persistent positive effects on later-life aging-related outcomes. On the other hand, exposure to excess chemicals and fertilizer effects might have adverse outcomes later in life, and the net long-term effect is ambiguous.

[1]Norman Borlaug, who led the initiative to develop high-yield crops, received a Nobel Prize in 1970. Various reports referred to Borlaug as "The Man Who Saved a Billion Lives" (MacAray, 2015).

Research has not yet explored whether early life exposure to this massive shock impacted later life aging-related outcomes.

There are at least three reasons to study the effects of the Green Revolution on long-term aging-related outcomes. First, the aging population is growing in the world and is (and will) be much higher in developing countries (Figure 1). By 2050, one in five people in poor nations will be over 60 years old. Falling fertility rates and increased life expectancy from improvements in health care, especially in Asia, have led to a rapidly aging population and, with it, a higher prevalence of age-related health problems. For example, a rapid increase in older populations is projected to also rise in Alzheimer's Disease and Related Dementias (ADRD), from about 47 million people worldwide in 2015 to more than 135 million in 2050, with particularly rapid increases projected for low- and middle-income countries. However, much of the evidence from the fetal origin literature focuses on high-income countries, yet there is an urgent need to understand how the long reach of childhood health affects long-term well-being in developing nations. Indeed, NIA has emphasized the urgent need to study aging and ADRD risk in developing countries because well-known patterns of aging documented in high-income countries (HICs) may not be generalizable in LMICs, where contexts differ dramatically from those experienced in HICs.[2] Secondly, investigating the underlying relationships in these contexts is all the more challenging given the lack of empirical data spanning the whole life course of individuals. Finally, the Green Revolution is an ongoing policy yet to be adopted in several parts of other developing countries. For instance, African countries started investing in these technologies in the last couple of decades. From a policy perspective, it is important to know whether some of the short-run benefits and costs of the Green Revolution also persist in the long term and whether to keep investing in these technologies or not.

The early life investment due to the Green Revolution may affect later life aging-related outcomes both positively and negatively, and the net effect is unclear. For instance, with the

[2] Leveraging Rarely-Investigated Populations for Research on Behavioral and Social Processes in an Aging Context Expert Meeting.

increase in exposure to the availability of food due to the GR during the birth year, we may expect better later-life health outcomes due to the availability of nutrition. On the other hand, exposure to the excess agrochemicals mixed in the water may subdue those positive health outcomes later in life. So, the direction of the net effect is ambiguous in this context. The research, however, is very limited in understanding whether and how early-life exposure to the massive shock of the GR impacted later-life cognitive function. The focus of later-life research is mainly on developed countries due to limited data available for developing countries, primarily due to the lack of detailed aging data in developing countries until recently. The lack of evidence on the long-term effects undermines the potential benefits (or costs) of this massive agricultural shock during the older age.

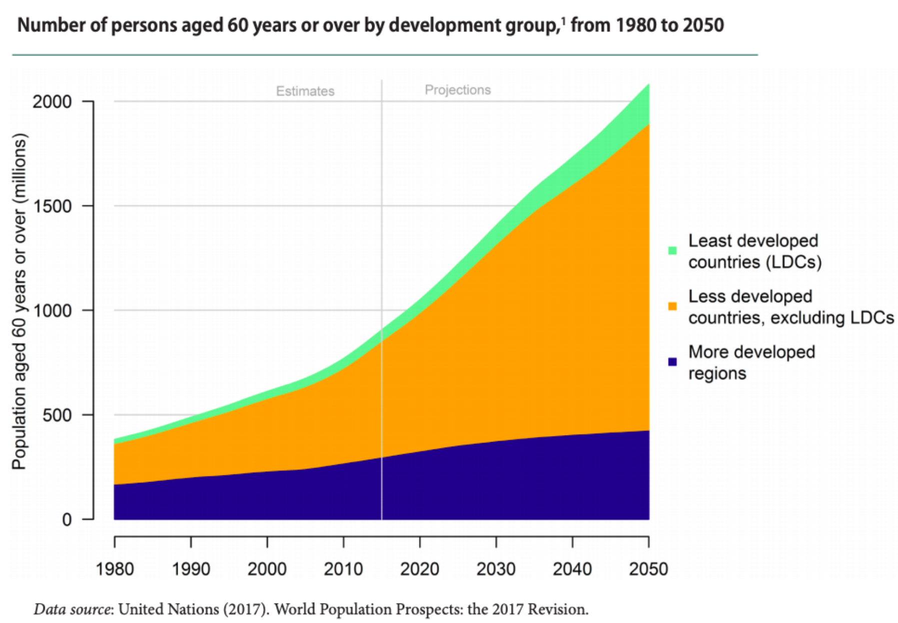


FIGURE 1: United Nations Report, 2017

This paper evaluates whether early-life exposure to the HYV developed under the Green Revolution affects long-term aging outcomes in India. To measure the exposure to the Green Revolution, we use yearly panel data of districts from 1966 to 1989 data from the Village Dynamics of South Asia (VDSA), which has information related to the HYV crops. We use the newly available first wave of the nationally representative Longitudinal Aging Study in India (LASI) data of individuals aged 45+. We match LASI and VDSA data using the birth district and birth year of the respondents from the LASI. The paper employs a generalized difference-in-differences (DID) design exploiting the temporal and spatial variation in the HYV crops. To address the temporal and spatial factors associated with the adoption of the Green Revolution, which might also affect cognitive health later in life, we include the birth district and birth year fixed effects. Alternatively, we also include birth state-specific linear time trends or birth state-by-year fixed effects.[3] Further, we explore the heterogeneous treatment effects of gender, castes, parental education, rurality, and heavily adopted Green Revolution Areas. Finally, we explore potential mechanisms through which early life exposure to the Green Revolution may affect later life outcomes, including education, chronic conditions, and other health outcomes.

We find weak evidence of the early life exposure to the Green Revolution on the later life cognitive function among our main sample. However, we find a heterogeneous treatment effect suggesting that exposure to the GR around the birth years significantly improved the later life cognitive function among the socially disadvantaged groups and people born in rural areas. Specifically, we find that one standard deviation increase in GR during early life improved these groups' later-life cognitive function between 0.08 to 0.13 standard deviation. We find that the early life exposruThe significant improvement in schooling among these groups explains some of the positive effects on general cognitive health. We rule out that the school construction was driving any positive gain in schooling and also rule out that improvement in height is driving the benefits in cognitive function.

This paper makes several contributions to the economics literature. First, we contribute to the literature on fetal origin by exploring the extent to which exposure to agriculture investment in the first years of life influences later life health and human capital. Fetal origins research is a relatively newer area of research in economics and has shown that changes in nutrition, stress, income, and the disease environment during pregnancy increase the risk for Type II diabetes, hypertension, coronary and artery disease (Almond, 2006, Hoynes

[3] The first takes into account any unobserved trending variables that may vary by state-specific cohorts, and the second accounts for any annual pattern in later life outcomes that may differ across states.

et al., 2016, Aizer *et al.*, 2016). Research suggests the importance of the prenatal and early childhood years in setting the foundations for life-long success (Barker, 1990, Almond and Currie, 2011). This paper fills the gap in the literature by studying the later-life impacts of one of the largest agricultural shocks in the world's history (Green Revolution) on later-life cognitive function and exploring several mechanisms of the effect.

Secondly, we contribute to the literature by understanding the linkages between the Green Revolution and the long-term impact on cognitive health at the individual level. A recent body of research in health suggests that the Green Revolution technologies contributed to a decline in child mortality across different parts of the developing world and, at the same time, some adverse effects on health due to an increase in agrochemical use and increasing metabolic syndrome (Brainerd and Menon, 2014, Sekhri and Shastry, 2020, Bharadwaj *et al.*, 2020, Gollin *et al.*, 2021, Carter *et al.*, 2021). A very limited number of studies explore the impact of the Green Revolution over several decades of exposure (Sekhri and Shastry, 2020). From a policy perspective, it is important to know whether some of the short-run benefits and costs of the Green Revolution also persist in the long term because Green Revolution is an ongoing policy yet to adopt in several parts of other developing countries. However, most of the above evidence in is either at the macro level or for relatively short-run effects. While we have enough evidence at the aggregate level, do the Green Revolution technologies affect long-term individual-level aging-related outcomes is not evident in the literature. We contribute to the literature to understand the long-run impacts of the Green Revolution at the individual level.

Third, we contribute to the literature on aging-related outcomes in low and middle-income countries (LMIC). Very little is known about the early-life investments and later-life aging-related outcomes in developing countries, where accelerated aging and limited clinical care have led to poorly understood aging and ADRD risk trajectories. That's why the National Institute of Aging (NIA) has emphasized the urgent need to study aging in developing countries. One of the primary reasons for the lack of evidence from developing countries is that detailed aging data in developing countries was not available until recently. We use the newly available data from the Longitudinal Aging Study in India (LASI), which is considered the largest aging data in the world, with over 72,000 respondents surveyed. The LASI data is comparable to the Health and Retirement Study (HRS) in the United States, which includes detailed health, economic, and social well-being of India's elderly population. We contribute to the literature on aging in developing countries by providence that has policy implications for the overall developing world to understand whether to keep investing in the Green Revolution technologies and whether to expand this policy to low Green Revolution regions.

2 Background

The Green Revolution started with the development of high-yielding crop varieties (HYV) for developing countries in the 1950s. HYVs of rice and wheat were developed in the mid-1960s and subsequently extended to other crops. The success of these HYVs is considered a "Green Revolution" (Evenson and Gollin, 2003). The adoption of the Green Revolution technologies has led to substantial improvement in economic growth. Vast research suggests that the Green Revolution technologies contributed to a substantial increase in crop production, food security, GDP per capita, and a decline in food prices, poverty, fertility, and child mortality across developing nations. Estimates suggest that 1% increase in the per hector agricultural production led to 0.4% reduction in poverty in short run and 1.9% in the long run (Pingali, 2012). There is a large literature suggesting that during the Green Revolution, farmers' income increased, demand for goods and services went up, and it stimulated the rural non-farm economy and increased new income and employment opportunities; real per capita incomes almost doubled in Asia, and overall poverty reduced. A very recent study suggests that A 10-year delay of the Green Revolution in 2010 would have cost 17% of GDP (gross domestic product) per capita to the developing-world population, and the cumulative GDP loss would have been 83 trillion US dollars (Gollin *et al.*, 2021).

India was among the early adopters of the technologies through the Green Revolution. Since wheat and rice yield and cereal production doubled from 1970 to 1995, cereal and calorie availability per person increased by 30%. The adoption of these hybrid varieties (HYV) of rice and wheat (and later other crops) also played a vital part in India's agriculture sector, which accounts for 23% of its GDP. Currently, 70% of rural households in India (population $\sim$ 630 million) still depend on agriculture for their livelihood.[4] The adoption of HYV of rice and wheat (and later other crops) played a vital part in India's agriculture sector, accounting for 23% of its GDP. Currently, 70% of rural households in India (population $\sim$ 630 million) still depend on agriculture for their livelihood.[5]

On the other hand, other studies document the adverse effects of the Green Revolution on people's health, loss of biodiversity of crops and soil, and unequal access to the HYV crops with high Castes and large farmers had more access to the resources, creating a social inequity. For instance, studies found that the Green Revolution may have had adverse effects on health due to an increase in agrochemical use and increasing metabolic syndrome (Brainerd and Menon, 2014, Sekhri and Shastry, 2020). Some studies document that the traditional rice varieties became non-existent, and India lost more than 100,000 varieties of indigenous rice. Similarly, mismanagement and overuse of chemical fertilizers and pesticides caused a reduction in crop diversity/crop rotation since HYV was mostly focused on wheat and rice. All of this caused the land to become infertile, and there was a loss of groundwater, an increase in deforestation, soil erosion (removal of the top fertile soil layer), and a loss of biodiversity. Finally, the distribution of the HYV crops also had an inequity by Castes and income and large and small farmers and between rural and urban areas.

Studies also suggest that gender also played a big role in distributing the benefits of GR. Women farmers and female-headed households gained less than their male counterparts (Pingali, 2012).

[4] Please check http://www.fao.org/india/fao-in-india/india-at-a-glance/en/.

[5] Please refer to http://www.fao.org/india/fao-in-india/india-at-a-glance/en/.

3 Data

3.1 Village Dynamics of South Asia (VDSA)

VDSA has the annual information on the area in hectares planted under high yield variant (HYV) for 281 districts and 19 states in India from 1966 to 2017. The HYVs are for the six major crops- rice, wheat, maize, finger millet, pearl millet, and sorghum. The data also has annual information on the area and production of 25 major and minor crops. Our main treatment variable is the ratio of HYV area to total cultivated area as in (Bharadwaj *et al.*, 2020). We sum the area planted under the HYV crops in each district in the year of birth. We then divide the sum by the total area cultivated under all crops in each district in a year. This gives us a share of the cultivated area planted under the HYV.[6]

Figure 2 shows the share of the total cultivated area planted under HYV for India over the period.[7] The adoption was rapid for rice and wheat compared to the other crops. Figure 3 describes the district-wise share of the high-yield crops averaging over the period of 1966 to 1989. There exists substantial variation in the adoption of high-yield crops by various districts over time. The adoption was rapid in the northern states compared to the other parts of India. In our identification strategy, we are going to explore these temporal and spatial variations.

3.2 Longitudinal Aging Study in India (LASI)

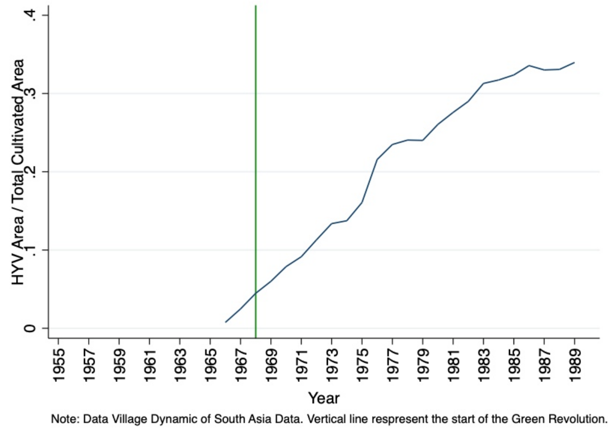
The LASI is the world's largest and India's first longitudinal aging study.[8] It is a nationally representative survey of more than 72,000 older adults aged 45+ and their spouses (irrespective of age) above in India's all 30 states and six union territories. A survey for the first wave was conducted in 2017-18, and the data was released in 2021. LASI is the first detailed scientific investigation of India's health, social determinants, and economic well-being of older

[6]We remove a small number of observations if the total HYV area is greater than the total cultivated area.

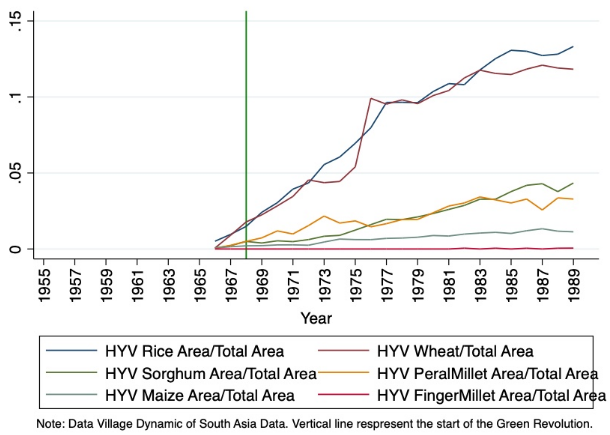
[7]This data are commonly used in the literature (Bharadwaj *et al.*, 2020).

[8]Details on LASI's first wave can be found in (Bloom *et al.*, 2021).

FIGURE 2: Share of Total Area Under High Yield Crops (by Year)



(a) High Yield Area Share- Combined



(b) High Yield Area Share- Separated

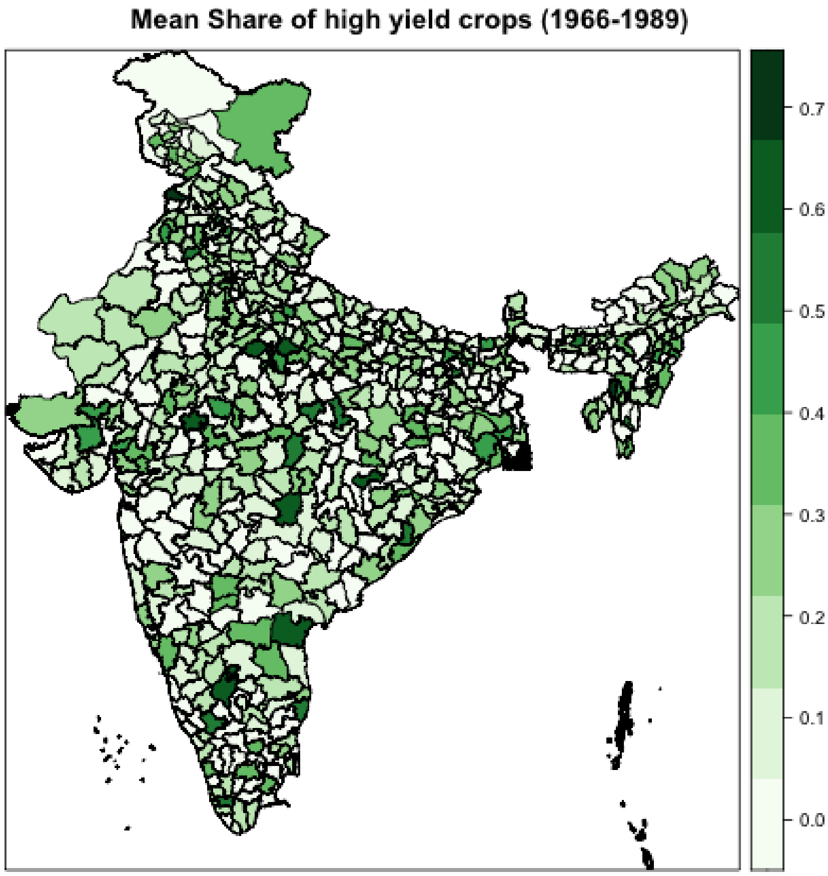
Note: This figure shows the trend in adopting HYV crops using VDSA data. The share of the total area under green evolution (high-yield crops) is the ratio of area planted to high-yield crops to the total cultivated area (both in hectares) in a birth district of an individual. Panel A shows the trend combined with all the HYV crops, and panel b shows the trend separately for each HYV crop. The vertical line is for the year 1968, which is the start year of the green revolution in India.

adults. The data includes the respondents' district and birth year, which helps merge with the VDSA data.

Respondents who were born from 1958 through 1989 were for whom the birth district is available in the data.[9] When we merge LASI data with the Green Revolution (VDSA) data

[9]We obtained the restricted data on the district of birth for almost half of the LASI sample, which was available in the public files of LASI.

FIGURE 3: Mean Share of High Yield Crops



Note: We merge LASI and VDSA data for the mean district share of HYV across all the birth cohorts for the period of 1966 to 1989.

using the district and birth year, we can match almost all the districts (342).[10] We have 281 districts that have experienced the green revolution starting from 1966, and the remaining 61 districts never have the green revolution.

3.3 Outcome Variables

3.4 Mental Health

Our primary outcome variable, the 'general cognitive score,' serves as a general cognitive factor score that represents the latent trait of the respondent's cognitive function. This

[10]We use the districts crosswalks files generously provided by Aaditya Dar.

score is derived using a graded response item response theory model outlined by (Muthén and Muthén, 2017). We follow the literature to use this score (Flood *et al.*, 2022). The score is specifically created based on including 11 common items and 42 non-common items shared between the LASI and the LASI-DAD (Diagnostic Assessment of Dementia) surveys. Importantly, the score is scaled to have a mean of 0 and a variance of 1 within the LASI-DAD population, ensuring comparability and consistency in measurement. One notable characteristic of this score is its insensitivity to the inclusion of items that rely on literacy. This aspect ensures that the score accurately reflects cognitive performance across individuals with varying literacy levels.

3.5 Physical Health

We use the total number of chronic conditions as our key outcome variable to measure physical health. This measure is calculated by using the positive responses to eight questions on 'ever had the following conditions: blood pressure, diabetes, cancer, lung disease, psych problems, arthritis, stroke, heart problems.'

3.6 Descriptive Statistics

We begin with some descriptive evidence of the Green Revolution and the LASI cohort. Table 1 shows the characteristics of the sample characteristics of the 37,146 LASI respondents of our sample from the first wave of LASI in 2018. The primary outcome variable (general cognitive score) has a mean of 0.52. The mean age of the respondent is 49. On average, the number of total chronic conditions is lower than 1; however, about 34% have some form of chronic conditions. About 62% of our sample is Women, and about half of the respondents were born in rural areas. On Average, one-third of the respondents have education above the primary level. The fathers of the respondents are more than twice as likely to attend school than their mothers, given the social stigma about women's education in India.

The average exposure to the Green Revolution from in-utero to age 2 was 8 %. Figure 2

TABLE 1: Descriptive Statistics for aged 45+ Respondents

	Mean	SD	Min	max	Obs
Green Revolution					
Avg. Treatment (pre-conception)	0.06	0.09	0.00	0.73	15770
Avg. Treatment (in utero to age 2)	0.12	0.13	0.00	0.72	15771
Avg. Treatment Age 3 to 5	0.18	0.15	0.00	0.81	15771
Avg. Treatment Age 6 to 8	0.23	0.17	0.00	0.85	15771
Avg. Treatment Age 9 to 11	0.27	0.19	0.00	0.90	15771
Avg. Treatment Age 12 to 14	0.30	0.20	0.00	0.92	15771
Avg. Treatment Age 15 to 17	0.32	0.20	0.00	0.93	15771
Avg. Rain(mm) VDSA	105.03	63.32	0.00	388.23	15771
Avg.Max Temp(c)	31.14	2.68	0.00	35.40	15771
Avg.Min Temp(c)	19.62	2.47	-1.60	24.80	15771
Individual Characteristics					
Cognition Score	0.51	0.87	-3.50	3.25	15718
Cognition $\geq$ 25 pct	0.75	0.43	0.00	1.00	15718
Height (Stdz.)	0.05	0.99	-4.45	4.47	14253
BMI	23.47	4.76	10.52	63.41	14259
Total Chronic Conditions	0.42	0.70	0.00	6.00	15771
Any Chronic Condition	0.32	0.47	0.00	1.00	15771
Ever had Diabetes	0.08	0.28	0.00	1.00	15715
Ever had High BP	0.20	0.40	0.00	1.00	15717
Ever had Heart Problems	0.02	0.13	0.00	1.00	15721
Birth Year	1969.78	2.36	1966.00	1974.00	15771
Male	0.42	0.49	0.00	1.00	15771
Attended School	0.58	0.49	0.00	1.00	15771
Above Primary Edu	0.35	0.48	0.00	1.00	15771
Birth Rural	0.51	0.50	0.00	1.00	15771
Father Went School	0.33	0.47	0.00	1.00	15771
Mother Went School	0.14	0.35	0.00	1.00	15771
Low Caste	0.72	0.45	0.00	1.00	15771
1961 Census					
Share Literate(age10 above)	0.30	0.14	0.00	0.72	15771
Share Rural Population	0.79	0.23	0.00	1.00	15771
Sex Ratio M/F	1.05	0.20	0.00	1.63	15771
Observations	15771				

Note: The table shows the summary statistics of the respondents from the first wave of the Longitudinal Aging Study in India (LASI) for the 45+ age group (born from 1974 to 1966). We merged Village Dynamics in South Asia (VDSA) data with LASI data using the birth district and birth year of the LASI respondents with 314 districts at that time. Refer to the text for the variable definitions.

shows the substantial increase in the adoption of the HYV crops over time. Similarly, Figure 3 shows the mean share of HYV crops across different districts in India, suggesting a substantial heterogeneity in the HYV adoptions in India.

4 Estimation Strategy

We study the long-term effect of early-life exposure to the Green Revolution. We follow (Bharadwaj *et al.*, 2020) to use a proxy for green revolution as the share of the total area planted under high-yield crops. In the basic specification, we use the ordinary least square (OLS) to estimate the following equation.

$$Y_{isdt} = \sum_{\tau=-4,\tau\neq-1}^{17} \beta_\tau HYV_{\tau(d,t)} + X'_{isdt}\gamma + \delta_t + \mu_d + \tau_{st} + \varepsilon_{isdt} \tag{1}$$

where Y_{idt} is the health outcomes of individual i, born in district d at year t. The measure of exposure to green revolution is $HY_{d,t}$, which is the share of the total area planted under high-yield crops in the birth district d at the birth year t. We include the exposure to the treatment by averaging the share of high-yield crops over pre-birth (5 years before the birth to 3 years before), around the birth (2 years before to age 5), early life period (age 6 to 11), and early childhood (age 12 to 17). We do this for various reasons, including to account for the potential measurement error in reporting the birth year. We add a vector of controls, X'_{idb}, average rainfall, temperature, gender, castes, an indicator if the respondent was born in the rural area, and an indicator if the father and mother went to school. We also control for the pre-treatment 1960 census variables- sex ratio, the share of the rural population, and literacy rate. We include birth district fixed effects μ_d that control for all the time-invariant characteristics of the district. We also include birth year fixed effects δ_b that control for the time-specific shocks affecting all the districts in the year of birth. We also include state of birth by year of birth fixed effects τ_{sb} to account for general annual variation in outcomes that may vary across states. Standard errors are clustered at the district of birth level.

For identification, we compare individuals from the same district who were exposed to varying levels of high-yield crops based on their years of birth, over and above any unobserved shocks to the cognition scores that vary by year of birth and any long-run trends (or annual pattern) in that individual's state (or region) of birth. The estimate β is the consistent estimate of exposure to the Green Revolution if, conditional on the district and birth-year fixed effects and controls, changes in the district-level yield of HY crops are not correlated with other factors that also affect long-term health. The primary period of analysis of our study is from 1966 to 1974 since the Green Revolution period is considered to begin in about 1966 and the youngest cohort of the LASI respondent was born in 1974.

5 Results

5.1 Main Results

In this section, we present our main findings. Panel (A) of Table 2 shows the effect of early life exposure to the high yield varieties (HYV) on later life cognitive function using the general cognition score. The first column shows an estimate for the specification that includes birth-district fixed effects and birth-year fixed effects. In the second column, we include four types of control variables- individual-level time-invariant, weather, parental education, and the 1961 Census. For individual controls, we include gender and caste; for weather controls, we include average rainfall and temperature; for parental controls, we include indicators father and mother went to school; and for the pre-treatment census variables, we include sex ratio, the share of the rural population, and literacy rate from the 1960 Census. In the third column, we add state-by-birth-year fixed effects to control for the annual variation in health outcomes that may vary across states. In the fourth column, we replace state-by-birth-year fixed effects with state-specific linear time trends to account for possible unobserved trending variables that may vary by state-specific cohort.

Column 1 in Table 2 shows that early-life exposure to the green revolution affects later-

TABLE 2: Effect of early life exposure to the HYV on mental and physical health

	Panel (A) Outcome: General Cognition Score				Panel (B) Outcome: Total Chronic Conditions			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Variables								
Pre-Conception	0.221	0.171	0.218	0.026	0.285**	0.268*	0.327*	0.426*
	[0.167]	[0.171]	[0.186]	[0.250]	[0.142]	[0.159]	[0.194]	[0.239]
In-utero to Age 2	0.109	0.058	0.089	0.416*	-0.006	0.065	0.214	0.211
	[0.192]	[0.158]	[0.171]	[0.234]	[0.199]	[0.198]	[0.236]	[0.274]
Observations	15,695	15,695	15,695	15,705	15,748	15,748	15,748	15,758
R-squared	0.14180	0.33291	0.33395	0.34351	0.06771	0.08104	0.08237	0.09240
Birth year FE	Y	Y	Y	Y	Y	Y	Y	Y
Birth District FE	Y	Y	Y	Y	Y	Y	Y	Y
Weights	Y	Y	Y	Y	Y	Y	Y	Y
Controls		Y	Y	Y		Y	Y	Y
State-Birth Y Trend			Y				Y	
State-Birth Y FE				Y				Y
Mean of Y	0.518	0.518	0.518	0.519	0.400	0.400	0.400	0.400

Note: This table shows the effect of early life exposure to the Green Revolution on later life cognitive function and total chronic conditions. The data are Village Dynamics of South Asia (VDSA) merged with the first wave (2018) of the Longitudinal Aging Study in India (LASI). The outcome variable is the general cognitive score. We include person weights. Standard errors are clustered at the birth district level. *** p<0.01, ** p<0.05, * p<0.10.

life cognitive function positively; however, the estimates are statistically insignificant. The estimates on the pre-conception are also statistically insignificant, suggesting evidence of the fulfillment of the parallel trend assumption. In column 2, we introduce controls, and the estimates decline by half; however, they are still insignificant. In column 3, with the state-by-birth-year trends, we also do not find a significant effect. Finally, column 4 of Table 2, which is our preferred specification with state-by-birth-year fixed effects, suggests that one standard deviation (SD) increase in the average HYV share during in-utero to age 2 improves the cognitive score by 0.41 and are statistically significant at 10% level. In Appendix Table 7, we also show the estimates with the full age profile from pre-conception to age 17. We find similar effects suggesting that in-utero exposure to the GR did not significantly affect the later life cognitive function.

In panel (B), we show the effects on later life physical health, using the total number of chronic conditions as an outcome. In our preferred estimates in column 8, we find that early life exposure (in-utero to age 2) to the GR increases the total number of chronic conditions; however, the estimates are not statistically significant. To further explore, we provide evidence on the heterogeneous treatment effects in the next section.

5.2 Heterogeneity Analysis

We further explore various heterogeneity in the effect of early life exposure to the GR on later-life cognitive function in Table 3. We mainly explore the treatment effects based on gender, caste, and region. First, we do not find any statistically significant effects on cognitive function among both men and women (columns 1 and 2), even though the coefficients are positive and large in magnitude. Secondly, we find a statistically significant increase in cognitive function among the low-caste respondents (column 3) but not for the high-caste individuals (column 4). Specifically, one SD increase in the average HYV share during in-utero to age 2 improves the cognitive score by 0.08 SD among lower castes. There are two possible explanations for the positive effects on lower castes. First, the lower caste households are more likely to be poorer and usually lack the financial and nutritional resources to invest in a child's development. We show in the descriptive statistics by castes that low castes have significantly lower access to GR, they are less likely to attend school, have lower educated parents, are less likely to stay in a literate population, and are more likely to reside in rural areas (Table B.1). With higher access to some of the resources through GR, one might expect improvement in the financial and nutritional resources for the low castes. This evidence is consistent with the literature that suggests better outcomes of GR for low-castes, like reduction in child mortality and increases in access to health facilities (Bharadwaj *et al.*, 2020, Munshi and Rosenzweig, 2009). The second explanation is about an increase in education among low castes. We explore some of these mechanisms in section 6.

Further, we do not find evidence of early-life exposure to the GR on later-life cognitive function for responders born in urban areas (column 5) but find a statistically significant increase in cognitive function among responders born in rural areas (column 6). This implies that the adoption of GR was mediated through agricultural income and rural development. Specifically, one SD increase in the HYV share during in-utero to age 2 improves the cognitive score among rural born by 0.10 SD. This evidence is also consistent with the literature suggesting the benefit of GR in reducing child mortality in rural areas (Bharadwaj *et al.*, 2020). Finally, the positive effect of GR is strongest for the low-castes born in rural areas (column 8), which improves the general cognitive score by 0.12 SD. In section 6, we show some of the potential channels for these positive gains in cognitive function. Finally, in Appendix subsection B.3, we show the heterogeneous treatment effects of the GR on physical health.

TABLE 3: Heterogenous Treatment Effect

	Outcome Variable: General Cognition Score							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Sample	Men	Women	Low Castes	High Castes	Urban	Rural	Rural High Caste	Rural Low Caste
Pre-conception	-0.273	0.188	-0.066	-0.081	0.097	-0.142	-0.312	0.100
	[0.388]	[0.278]	[0.277]	[0.466]	[0.405]	[0.249]	[0.649]	[0.363]
In-utero to Age 2	0.577	0.319	0.639**	-0.373	0.335	0.803***	-0.072	0.947***
	[0.360]	[0.285]	[0.272]	[0.451]	[0.348]	[0.284]	[0.634]	[0.358]
Observations	6,556	9,117	11,323	4,341	7,640	8,023	2,166	5,813
R-squared	0.287	0.325	0.342	0.391	0.323	0.369	0.463	0.373
Birth year FE	Y	Y	Y	Y	Y	Y	Y	Y
Birth District FE	Y	Y	Y	Y	Y	Y	Y	Y
Controls	Y	Y	Y	Y	Y	Y	Y	Y
State-Birth year FE	Y	Y	Y	Y	Y	Y	Y	Y
Weights	Y	Y	Y	Y	Y	Y	Y	Y
Mean of Y	0.739	0.204	0.434	0.755	0.663	0.322	0.541	0.244

Note: This table shows the effect of early life exposure to the Green Revolution on later life cognitive function. The data are Village Dynamics of South Asia (VDSA) merged with the first wave (2018) of the Longitudinal Aging Study in India (LASI). The outcome variable is the general cognitive score. We include person weights. Standard errors are clustered at the birth district level. *** p<0.01, ** p<0.05, * p<0.10.

6 Mechanism

In subsection 5.2, we find the heterogeneous treatment effect of the early life exposure to the Green Revolution on the later life cognitive function, mainly for the low-castes and rural areas. We unpack some of the channels through which this effect may exist. First, we test whether better cognition mediates through better nutrition by using 'height' as a proxy, which is one of the predictors for better early life investments. Secondly, we study whether education is a contributing factor to better cognitive function. Finally, we study school construction as one of the mediators to rule out if the construction of schools was driving some of the positive effects.

6.1 Height

We test whether early life exposure to the Green Revolution also affects other later life health outcomes that may explain the benefits in the positive cognitive function. We study height as one of the outcomes. We standardized the height based on gender. The estimates are documented in Table 4.

TABLE 4: Heterogenous Treatment Effect on Height

	Outcome Variable: Standardized Height							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Sample	Men	Women	Low Castes	High Castes	Urban	Rural	Rural High Caste	Rural Low Caste
Pre-conception	-0.016	-0.147	0.033	-0.224	0.300	-0.522	-1.114	-0.209
	[0.635]	[0.376]	[0.471]	[0.587]	[0.574]	[0.465]	[0.683]	[0.584]
In-utero to Age 2	0.854	-0.333	0.421	-0.218	0.185	0.274	1.000	-0.341
	[0.639]	[0.487]	[0.416]	[0.613]	[0.641]	[0.516]	[0.737]	[0.642]
Observations	5,880	8,325	10,376	3,824	6,861	7,332	1,927	5,360
R-squared	0.165	0.140	0.117	0.221	0.150	0.154	0.294	0.160
Birth year FE	Y	Y	Y	Y	Y	Y	Y	Y
Birth District FE	Y	Y	Y	Y	Y	Y	Y	Y
Controls	Y	Y	Y	Y	Y	Y	Y	Y
State-Birth year FE	Y	Y	Y	Y	Y	Y	Y	Y
Weights	Y	Y	Y	Y	Y	Y	Y	Y
Mean of Y	0.030	0.009	-0.027	0.162	0.025	0.016	0.129	-0.025

Note: This table shows the effect of early life exposure to the Green Revolution on later life cognitive function. The data are Village Dynamics of South Asia (VDSA) merged with the first wave (2018) of the Longitudinal Aging Study in India (LASI). The outcome variable is the standardized height. We include person weights. Standard errors are clustered at the birth district level. *** p<0.01, ** p<0.05, * p<0.10.

If GR helped the weakest people survive, one would expect those people might have worse health outcomes. We do not find evidence that early-life exposure to GR affects later-life height for any of the groups. This evidence is also consistent in the literature that suggests GR does not affect heights among children (Bharadwaj *et al.*, 2020).

6.2 Education

We test whether the improvement in cognitive function among the subgroups is attributed to education. We use outcome on education as an indicator that takes the value of 1 if they attended any school and 0 otherwise. Table 5 shows the estimates of early life exposure to the green revolution on education. The magnitudes in columns 3 and 8 show significant improvement in the likelihood of attending school for low-castes (10% level) and low-castes born in rural areas (1% level).

TABLE 5: Heterogenous Treatment Effect on Schooling

	Outcome Variable: Attended School							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Sample	Men	Women	Low Castes	High Castes	Urban	Rural	Rural High Caste	Rural Low Caste
Pre-conception	-0.045	-0.257*	-0.087	-0.539*	0.016	-0.259	0.000	-0.382*
	[0.235]	[0.148]	[0.137]	[0.281]	[0.206]	[0.173]	[0.396]	[0.197]
In-utero to Age 2	0.078	0.263	0.316*	-0.753**	0.018	0.317	-0.726	0.678***
	[0.256]	[0.182]	[0.176]	[0.322]	[0.235]	[0.206]	[0.490]	[0.226]
Observations	6,582	9,144	11,363	4,355	7,676	8,040	2,170	5,827
R-squared	0.250	0.380	0.328	0.341	0.297	0.386	0.426	0.393
Birth year FE	Y	Y	Y	Y	Y	Y	Y	Y
Birth District FE	Y	Y	Y	Y	Y	Y	Y	Y
Controls	Y	Y	Y	Y	Y	Y	Y	Y
State-Birth year FE	Y	Y	Y	Y	Y	Y	Y	Y
Weights	Y	Y	Y	Y	Y	Y	Y	Y
Mean of Y	0.677	0.403	0.506	0.727	0.630	0.475	0.651	0.412

Note: This table shows the effect of early life exposure to the Green Revolution on later life cognitive function. The data are Village Dynamics of South Asia (VDSA) merged with the first wave (2018) of the Longitudinal Aging Study in India (LASI). The outcome variable is whether the respondent went to school or not. We include person weights. Standard errors are clustered at the birth district level. *** p<0.01, ** p<0.05, * p<0.10.

6.3 Construction of Schools

We explore one of the first evidence on whether the green revolution also affects building more schools since we have seen that there is an increase in the level of schooling.This might also explain the positive effects on cognitive functions. We use school administration data for the year 2015-16 DISE, which has information on over 1.5 million schools in India in 2015-16 that have the year when the school was constructed. The data goes back to schools constructed in the 1850s.

We merged VDSA data with DISE data using the district and year of construction. We cross-walked the districts from DISE data in 2015-16 to the 1960s districts to match with the VDSA data. We restrict the sample period to 1966-1989. The primary treatment is the same as before, i.e., the share of HYV crops. The outcome variables are the total number of schools in a district in a given year in all the above categories. We also calculate the rural and urban schools in each of these categories. We control for the 1961 census district-level share of literate aged 5+ population, share of the rural population, and male-female ratio; for each, we include the linear time trend.

TABLE 6: Effect of Green Revolution on the Rural School Construction

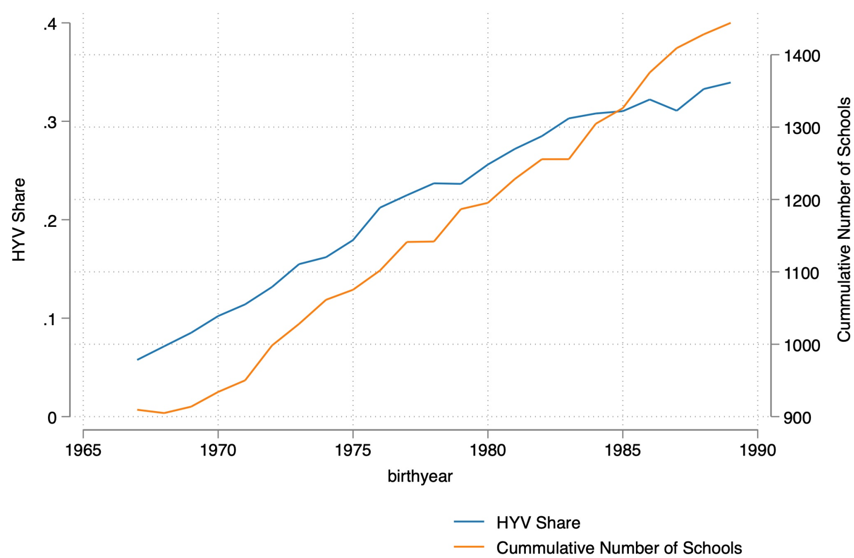
	(1)	(2)	(3)
VARIABLES	Rural Schools	Rural Schools	Rural Schools
HYV Area / Cultivated Area	-14.74***	-4.58	-0.88
	[5.08]	[4.41]	[4.78]
Observations	6,968	6,968	6,968
R-squared	0.29	0.32	0.53
District FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Census Controls	Yes	Yes	Yes
Mean of dependent variable	21.79	21.79	21.79
State-Year Trend		Yes	
State-Year FE			Yes

Robust standard errors in brackets
*** p<0.01, ** p<0.05, * p<0.1

We calculate the total number of schools constructed in each district in a given year. Also, we categorized the schools as *total schools, primary only, primary and middle, middle and high school, and high school only.* Except for the *total schools*, one caveat of categorizing the schools in this way is that they are based on the lowest and highest class reported in the data. However, the lowest and highest class reflect the current class status in the school and not necessarily the structure of schools during the study period (1966-1989).

7 Conclusion

FIGURE 4: Green Revolution and Number of Schools



Note: We merge LASI and DISE for the period of 1966 to 1989.

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Appendices

A Results

TABLE 7: Effect of early life exposure to the HYV on the cognition score

	Outcome Variable: General Cognition Score			
	(1)	(2)	(3)	(4)
Variables				
Pre-Conception	0.29606*	0.22135	0.22495	-0.04485
	[0.16192]	[0.16145]	[0.17898]	[0.23559]
In-utero to Age 2	-0.00712	0.02608	0.02483	0.37579
	[0.20553]	[0.16755]	[0.17026]	[0.23499]
Avg. Treatment Age 3 to 5	0.38829	0.22497	0.19956	0.25412
	[0.24863]	[0.20685]	[0.22396]	[0.27781]
Avg. Treatment Age 6 to 8	-0.26672	-0.45513**	-0.43373**	-0.64471**
	[0.21245]	[0.19121]	[0.19986]	[0.25248]
Avg. Treatment Age 9 to 11	0.01967	-0.05172	-0.06061	0.15995
	[0.30993]	[0.27132]	[0.28688]	[0.30788]
Avg. Treatment Age 12 to 14	-0.41009	-0.43836*	-0.31477	-0.07280
	[0.31487]	[0.26223]	[0.28760]	[0.25999]
Avg. Treatment Age 15 to 17	0.02822	0.09798	0.08506	0.09897
	[0.20924]	[0.17399]	[0.19180]	[0.19999]
Observations	15,695	15,695	15,695	15,705
R-squared	0.14230	0.33354	0.33434	0.34396
Birth year FE	Y	Y	Y	Y
Birth District FE	Y	Y	Y	Y
Weights	Y	Y	Y	Y
Mean of Y	0.518	0.518	0.518	0.519
Controls		Y	Y	Y
State-Birth year Trend			Y	
State-Birth year FE				Y

Note: This table shows the effect of early life exposure to the Green Revolution on later life cognitive function. The data are Village Dynamics of South Asia (VDSA) merged with the first wave (2018) of the Longitudinal Aging Study in India (LASI). The outcome variable is the general cognitive score. We include person weights. Standard errors are clustered at the birth district level. *** p<0.01, ** p<0.05, * p<0.10.

B Heterogeneity

B.1 Descriptive Statistics by Castes

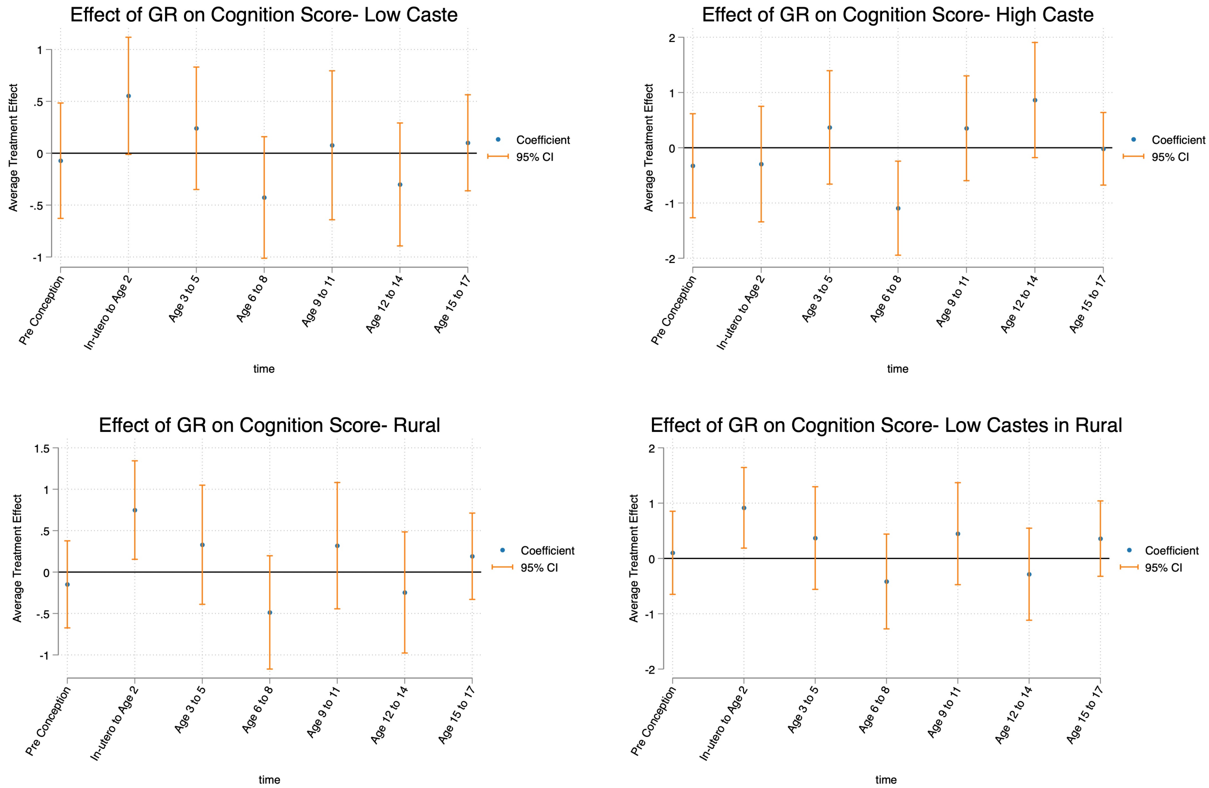
	High Castes	Low Castes	Difference	p-value
Treatment -1 to +2	0.13	0.12	0.01	0.00
Avg. Rain(mm) VDSA	109.34	103.40	5.94	0.00
Avg.Max Temp(c)	30.63	31.34	-0.71	0.00
Avg.Min Temp(c)	19.12	19.81	-0.69	0.00
Cognition Score	0.74	0.41	0.33	0.00
Height (Stdz.)	0.20	-0.01	0.21	0.00
BMI	24.71	23.01	1.70	0.00
Total Chronic Conditions	0.50	0.40	0.10	0.00
Any Chronic Condition	0.38	0.30	0.07	0.00
Male	0.43	0.41	0.02	0.08
Attended School	0.75	0.52	0.23	0.00
Above Primary Edu	0.52	0.28	0.24	0.00
Birth Rural	0.50	0.51	-0.01	0.32
Father Went School	0.48	0.27	0.21	0.00
Mother Went School	0.26	0.10	0.16	0.00
Share Literate(age10 above)	0.33	0.28	0.04	0.00
Share Rural Population	0.76	0.80	-0.04	0.00
Sex Ratio M/F	1.09	1.04	0.06	0.00
Observations	4,355	15,718		

B.2 Effect on Cognition with Full Age Profile

B.3 Results on Physical Health

Panel (B) of Table 2 shows the effect of early life exposure to the high yield varieties (HYV) on later life physical health using the total number of chronic conditions as an outcome. We further explore the heterogenous treatment effects in Table 8. Columns 1 and 5 show that early life exposure to the GR increases the probability of any chronic condition for men (significant at 5% level) and people living in urban areas (significant at 10% level). Similarly, in Table 9 Column1 shows that early life exposure to the GR increases the probability of ever having diabetes for men (significant at 10% level). These conclusions are consistent with the recent literature (Sekhri and Shastry, 2020).

FIGURE 5: Effect on Cognition with Full Age Profile



Note: This figure shows the effect of GR at different age groups on the Cognition score for different groups. The coefficients and the 95% confidence intervals are shown.

TABLE 8: Effect of early life exposure to the HYV on the Chronic Conditions

	Outcome Variable: Any Chronic Conditions							
Sample	(1) Men	(2) Women	(3) Low Castes	(4) High Castes	(5) Urban	(6) Rural	(7) Rural High Caste	(8) Rural Low Caste
Pre-conception	0.052	0.464**	0.118	0.592*	0.292	0.291	0.374	0.242
	[0.243]	[0.214]	[0.232]	[0.312]	[0.267]	[0.224]	[0.428]	[0.261]
In-utero to Age 2	0.526**	-0.103	0.124	0.467	0.442*	-0.024	0.430	-0.058
	[0.255]	[0.185]	[0.189]	[0.361]	[0.265]	[0.225]	[0.484]	[0.272]
Observations	6,582	9,144	11,363	4,355	7,676	8,040	2,170	5,827
R-squared	0.126	0.108	0.101	0.172	0.127	0.123	0.252	0.147s
Birth year FE	Y	Y	Y	Y	Y	Y	Y	Y
Birth District FE	Y	Y	Y	Y	Y	Y	Y	Y
Controls	Y	Y	Y	Y	Y	Y	Y	Y
State-Birth year FE	Y	Y	Y	Y	Y	Y	Y	Y
Weights	Y	Y	Y	Y	Y	Y	Y	Y
Mean of Y	0.269	0.354	0.286	0.355	0.283	0.334	0.386	0.314

Note: This table shows the effect of early life exposure to the Green Revolution on whether the respondent has any chronic condition. The data are Village Dynamics of South Asia (VDSA) merged with the first wave (2018) of the Longitudinal Aging Study in India (LASI). The outcome variable takes value 1 if the respondent reported of having any chronic condition and 0 otherwise. We include person weights. Standard errors are clustered at the birth district level. *** p<0.01, ** p<0.05, * p<0.10.

TABLE 9: Effect of early life exposure to the HYV on Diabetes

	Outcome Variable: Ever had Diabetes							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Sample	Men	Women	Low Castes	High Castes	Urban	Rural	Rural High Caste	Rural Low Caste
Pre-conception	0.033	0.075	0.127	-0.077	0.132	-0.013	-0.210	0.026
	[0.111]	[0.122]	[0.090]	[0.190]	[0.134]	[0.121]	[0.301]	[0.115]
In-utero to Age 2	0.298*	-0.206	0.106	-0.170	0.183	-0.063	-0.414	0.051
	[0.168]	[0.131]	[0.113]	[0.227]	[0.157]	[0.121]	[0.320]	[0.111]
Observations	6,556	9,114	11,333	4,329	7,643	8,017	2,162	5,812
R-squared	0.113	0.094	0.089	0.163	0.098	0.107	0.292	0.129
Birth year FE	Y	Y	Y	Y	Y	Y	Y	Y
Birth District FE	Y	Y	Y	Y	Y	Y	Y	Y
Controls	Y	Y	Y	Y	Y	Y	Y	Y
State-Birth year FE	Y	Y	Y	Y	Y	Y	Y	Y
Weights	Y	Y	Y	Y	Y	Y	Y	Y
Mean of Y	0.081	0.076	0.072	0.099	0.083	0.074	0.096	0.065

Note: This table shows the effect of early life exposure to the Green Revolution on whether the respondent ever had diabetes. The data are Village Dynamics of South Asia (VDSA) merged with the first wave (2018) of the Longitudinal Aging Study in India (LASI). The outcome variable takes value 1 if the respondent reported of having diabetes ever and 0 otherwise. We include person weights. Standard errors are clustered at the birth district level. *** p<0.01, ** p<0.05, * p<0.10.