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Abstract

Height is the result of a complex process of growth that begins at birth and reaches the end in early adulthood. This paper studies the determinants of height from birth to maturity. A height production function is specified whose structure allows height to be the result of the accumulation of inputs (i.e., nutrition and diseases) over time. The empirical specification allows the causal identification of the age specific effects of both nutrition and diseases on height. Rich longitudinal data on Filipino children followed for more than 20 years is used. Considering the differences in growth patterns between boys and girls, the results show the existence of two critical periods for the formation of height: infancy and puberty. In particular, diseases play a major role. Diseases experienced in the second year of life have a large and negative impact on height, but the largest reduction in height is due to diseases experienced during puberty.

JEL-Classification: I10; I12; O15; C13.

Keywords: height; health; early-life events; production function; Philippines.

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1 Introduction

Starting in the 1970s, anthropometric measures have increasingly been used in the social sciences as indicators of social well-being. Since then, adult height has been considered an indicator of the general health status in life, of the relative risk of survival, and labor productivity (Fogel, 1986). In particular, Case and Paxson (2008) explain the positive correlation between adult height and labor productivity by showing that height is positively associated with cognitive ability. They show that both cognition and height are driven by early childhood investments and therefore cognitive achievements are correlated with height, and wages are affected by cognitive skills. Poor health can explain both low height and low labor productivity. This is more evident in developing countries where living conditions are poor.[1] However, adult height is just the final result of a not-well-known process of growth that involves many different mechanisms and variables, and most of the common evidence looks at adult height (Steckel, 2009). It is therefore necessary to investigate the factors driving height, since understanding the determinants of height is important in order to understand health (Deaton, 2007).

In this paper I study the determinants of height from birth to maturity in a developing country. To do that, I build and estimate a height production function.

To motivate the specification of a height production function, I follow Steckel's (2009, pag. 7-8) reasoning:

> *...it is useful to think of the body as a biological machine, which*

[1] The fact that height increases wages or productivity is reported in: Behrman and Deolalikar (1989); Haddad and Bouis (1991); Steckel (1995); Thomas and Strauss (1997); Croppenstedt and Muller (2000); Schultz (2002); Dinda and Gangopadhyay (2006).

consumes food as fuel - a blend of calories, protein, micronutrients and other ingredients. This machine expends fuel ... to breathe, keep warm, circulate the blood and so forth, and in physical effort, fighting infection and physical growth. ... The body's first priority is to survive, and growth stagnates or takes a back seat under conditions of inadequate net nutrition...

Similar to the production process of a firm, the body can be considered a machine that combines different inputs through a particular technology to produce an output that in this case is height. The reason for estimating a production function is to find the *ceteris paribus* effects of each of the inputs. If I consider caloric intake and diarrhea as two of the inputs, the questions to answer are: "How does an exogenous change in caloric intake, holding all other inputs constant, affect height?" And "How does an exogenous change in diarrhea episodes, holding all other inputs constant, affect height?" And "At which age are those changes more relevant?" My intention is to find the technological parameters that answer the previous questions.

This paper uses the Cebu Longitudinal Health and Nutrition Survey (CLHNS), which is a rich longitudinal survey of a cohort of Filipino children followed from conception, in 1983-84, to 2005. The data allow the derivation of a height production function, from birth to maturity.

In particular, I study height as the result of the accumulation of several factors over time, identifying the direct effects of its determinants.[2] The determinants of

[2]Todd and Wolpin (2003, 2007) consider different methods for modeling the production function for cognitive skills to account for the fact that child development is a cumulative process depending on the history of family, on school inputs and on innate ability. They consider different specifications

height can be divided into non-genetic factors, genetic factors and the age when height is measured. The principal non-genetic factor is net nutrition which is the difference between food intake and the losses to activities and to diseases (Bozzoli et al., 2009). In developed countries there is evidence that genetic factors explain 80 percent of the variation in adult height and the rest is due to non-genetic factors. The proportion of the variation due to genetics seems to be less important when environmental stress is strong, for example in developing countries (Silventoinen, 2003). Therefore, the interplay between nutrition and diseases, and the understanding of which are the critical growth periods become crucial.

There is an extensive research that demonstrates the importance of early childhood investments for child health, growth, skills development, and labor outcomes later in life (see for example, Glewwe and King, 2001; Schultz, 2002; Cunha and Heckman, 2008; Maluccio et al., 2009; Almond and Currie, 2011, and references therein). This paper extends the literature by considering also later periods of life until the body maturation.[3] The main contribution of this work is the identification of critical periods that affect the entire process of height formation, emphasizing the relative importance of diseases versus nutrition. The analysis shows that the magnitude of the inputs effects during *infancy* and *puberty* are the highest. The results of this paper are in line with the increasing literature on the long term effects of early childhood conditions, as well as new work on the critical influences of adolescence

of the skill production function that rely on different assumptions and data limitation. I follow the same approach to study the process of height formation and I clearly explain the assumptions made to identify the technological parameters of the height production function.

[3]See Strauss and Thomas (2008) for the review of studies about health over the life cycle.

on health (van den Berg et al., 2014).[4] This might be important to design policy interventions that target individuals in these critical periods, and also in the years before chronic conditions affect adolescence development.

The paper is structured as follows. In Section 2, I develop a model for studying the process of height formation, and I present the empirical specification. Section 3 presents the data and a detailed description of the variables used. Section 4 describes the empirical results. In Section 5, I present some robustness checks. Finally, Section 6 concludes.

2 The height production function

In this section I present a model for the height production function. I am interested in technological parameters such as the effect of an exogenous change in one input, keeping all others constant. The technology that links inputs and output is fixed. It is created by nature and cannot be controlled. Economic agents play a negligible role in choosing some of the inputs, since the inputs they can choose are nutrition and diseases in the sense of prevention of diseases. They cannot choose either the age or the timing of children's growth.

It is widely known that height depends on the current age and on past inputs, such as health care practices, nutrient intake, disease incidence and genetic factors. A person's height is therefore a cumulative indicator because growth is a cumulative process by which past inputs and genetic endowment are combined in order to obtain

[4]Also Akachi and Canning (2007) find birth and adolescence to be critical periods, but they use cross-section data and mortality rate, GDP per capita, and protein intake as determinants of the adult height.

height.

Let me define the height production function that relates the height measured at age t to all previous investments in the child. Suppose that for $t = 0, \ldots, T$ and $i = 1, \ldots, N$ I have:

- H_{it} the observed height for child i at age t,
- $f(t)$ an age trend,
- $\mathcal{X}_{i,t}$=$(X_{it}, X_{it-1}, \ldots, X_{i1}, X_{i0})$ the vector of inputs for child i from birth to age t,
- μ_i the child's biological endowment,
- ϵ_{it} a shock to the height production for child i at age t.

Then the **height production function** is given by:

$$H_{it} = h_t[f(t), \mathcal{X}_{i,t}, \mu_i, \epsilon_{it}]$$

where the inputs $\mathcal{X}_{i,t}$ are nutrition and diseases.

To study empirically the height production function, I make different assumptions.[5]

[5]See Todd and Wolpin (2003, 2007) for a detailed description of different specifications of a skill production function for children and the assumptions made for the empirical specifications. The similarity of the two studies is that the processes of both height formation and achievement are cumulative processes that depend on the history of inputs chosen by the families, are due to the environment or are simply inherited genetically.

(A) I assume that the child's biological endowment is determined at conception and it is constant over time.[6]

(B) I assume that the height production function is linear in the inputs and in the unobserved endowment, and that the effects of the inputs depend on the child's age. The true technology that links inputs and output is unknown. This functional form implies that there is not complementarity and this means that all investments should be concentrated in one period, during the high-return period, and no investments should be made when the returns are low. This is in line with most biomedical and epidemiological studies in the "early influences" literature. They show that investments in early childhood produce effects on adult outcomes. But the effects may be bigger as individuals age, because the child's development is divided in different stages that have different influences on the adult outcomes.[7] Hence, I obtain the following model:

$$H_{it} = f(t) + X_{it}\beta_t + X_{it-1}\beta_{t-1} + \cdots + X_{i1}\beta_1 + X_{i0}\beta_0 + \mu_i + \epsilon_{it}. \tag{1}$$

(C) I also assume that the time-varying coefficient β_s ($s = 0, 1, \ldots, t$) depends only on the child's age s. For example, the impact of the infancy inputs on the final height is the same as the impact on height at age 8.[8]

[6]Case and Paxson (2008) hypothesize an endowment determined at birth that changes according to the child's age. But their time-invariant individual effect also includes the environmental factors that in my study are observed and considered as further regressors in the model. Furthermore, I suppose that the gene-environment interactions are the same for each age of the child.

[7]It also seems plausible that there should be interactions among inputs, but their inclusion in the model is empirically intractable due to the limited number of observations.

[8]In a recent working paper, Griffen (2013) estimates a height production function using data from Guatemala on children up to age 7 years. His model relies also on two different and stronger assumptions: both contemporaneous and lagged inputs have constant effects by age.

2.1 Empirical specification

In order to estimate (1), I consider a within-child fixed effects specification (FE).[9] This specification is feasible because the children are observed more than once, and several outcome and input measurements are available.[10] In particular, consider differencing (1) by age:

$$\Delta_{it} = H_{it} - H_{it-1} = f(t) - f(t-1) + X_{it}\beta_t + \epsilon_{it} - \epsilon_{it-1} \tag{2}$$

The βs parameters resulting from the above equation (2) are the specific input effects for the inputs applied between the two periods. The age trend is expressed as a linear and a quadratic term.

The within-child fixed effect estimator eliminates the endowment from equation (2), dealing with the endowment heterogeneity. However, there might be potential endogeneity of the nutrition and disease inputs. The fixed effects allow a permanent change in the inputs. On the other hand, contemporaneous inputs could respond to previous shocks causing endogeneity. If, for example, a child is very small at a certain point in time, and the parents give him more food to help his/her growth,

[9] Cebu-Study-Team (1992) and Liu, Mroz, and Adair (2009) use the same data to estimate different health production functions. They adopt an another specification that includes lagged values of the outcome in the model instead of the historical inputs. In the cognitive skills literature this specification is called the "value added" specification. When data on past inputs are missing, the use of the lagged outcome is quite common. However, the lagged outcome is correlated with the shock by construction, and additional lagged outcome measures can be used as instruments to address endogeneity. Since past inputs are available, and I am specifically interested in their impact on height, I do not consider this specification. A lagged measure of height would capture almost all of the variability and it would not allow me to distinguish between the effects of nutrition and non-nutrition inputs.

[10] A within family specification would be interesting, but the data contain anthropometric measurements of some siblings but not all the information about siblings' net nutrition.

this is not captured by the fixed effect and produces endogeneity.

I address endogeneity by using variation in village-level food prices and other village and household characteristics as instrumental variables (IV) to estimate the production parameters via IVFE.

The within-child fixed effect estimator assumes that differenced omitted inputs are orthogonal to the differenced included inputs or that omitted inputs are constant over time and they are eliminated by the fixed effect estimators. In the Appendix, I report the estimates of a hybrid production function where I include family income as proxy for the time-varying omitted variables.

Section 5 reports discussion and robustness checks on attrition and omitted variables bias.

3 Data

The country of interest is the Philippines, and in particular the Metropolitan Cebu or Metro Cebu. Cebu is a province in the Philippines and it consists of Cebu Island and 167 surrounding islands.

The CLHNS, is a longitudinal survey of a cohort of Filipino women who gave birth between May 1, 1983 and April 30, 1984.[11] A stratified and single stage sampling procedure was used to randomly select 33 communities or barangays from the Metropolitan Cebu. Of them, 17 are urban communities and 16 are rural communities. The baseline survey includes 3327 women who were interviewed during the 6th

[11] For more information about the project and to download the data, visit `http://www.cpc.unc.edu`.

to 7th month of pregnancy. All pregnant women of the barangay and the births were identified, and 3,080 non twin live births were consequently followed in the survey. Around 2,600 households were analyzed for the first 2 years. The children who were born during that period, their mothers, other caretakers, and selected siblings were followed through subsequent surveys conducted in 1991-2, 1994-5, 1998-9, 2002 and 2005. Apart from those last surveys, bimonthly surveys were conducted in the first 2 years of life of the children.

The initial focus of the survey was to collect information about the infants' feeding patterns. Later on, when the children were followed through adolescence and into young adulthood, the objective changed to a longitudinal intergenerational study of health. The data spans over 20 years and covers issues such as health, nutrition, water quality and sanitation. It contains detailed information about the mother's health and behavior during pregnancy, such as health care practices or smoking behavior, children's education, household and individual economic situation, demographic information, family planning, intra-household relationships, and reproductive health.

Of special interest for my study is the rich collection of anthropometric measurements from birth to age 22, as well as complete disease and nutrition information. Since the data have information at the individual, household and community levels, it is possible to study the long-term effects of prenatal and early childhood nutrition and health on later adult outcomes, matching physical and socio-economic information.

The data is composed by 18 waves in total, 13 collected during infancy and 5 during pre-puberty and puberty. It is important to notice that individuals are not surveyed at the same age. The waves of the panel are not evenly spaced. Table 1 reports the children's age at the time of the different follow-ups.

Insert table 1 here.

The CLHNS is not a representative sample of the Philippines population, nor of all Cebu because of the criterion of selection based on fertility. However, Mendez and Adair (1999) find that the sample is representative of the ever married women with at least one child in the early '80s.

The *outcome* variable for this paper is raw height reported in centimeters. Height and weight were measured every two months for the first two years of life, and later during childhood and adolescence by the field staff in Cebu. The measurements were taken by specialists and this is a great advantage compared to the self-reported heights common to many datasets. Reliability checks were made to avoid heaping and other errors in the measurements. The distribution of height by age and sex is shown in Figure 1.

Insert figure 1 here.

The inputs of the height production function can be divided into inputs during infancy, and inputs during pre-puberty and puberty. As previously specified the most relevant non-genetic inputs are nutrition and diseases.

3.1 Inputs during infancy

During the infancy period, the data are collected bimonthly. I aggregate the inputs between birth and age 1 year and between age 1 and 2.[12] In particular, I consider

[12] I follow Glewwe and King (2001) that study the effects of malnutrition during infancy on children's cognitive development using the CLHNS data. They aggregate the inputs over the first

caloric intake, which is a good aggregate indicator of nutrition, even if it does not capture the role of micronutrients. The CLHNS data provide precise information about the individual's diet based on 24-hour dietary recalls or a quantitative food frequency questionnaire. Daily energy intake is calculated from 24-hour dietary recalls during the surveys from birth to age 2 years.[13] The caloric intake for infants is exclusive of breast milk. I compute the average caloric intake in the first and second year of life. Since this does not entirely capture the infant's nutrition, I also consider breast feeding.

Breast feeding has been found to improve both cognitive ability and adolescent health and therefore positively affect long-term academic achievement (Rees and Sabia, 2009). Belfield and Kelly (2012) find that breast feeding for at least 6 months and not formula feeding at birth are negatively associated with obesity and positively associated with cognitive performance. In the analysis I consider the average time the child was breastfed in the first and second year.[14]

As for the diseases, I consider if the infant had feeding problems in the few hours after birth (baseline or wave 0) and diarrhea episodes later on (waves 1 to 12). In fact, some diseases reduce the absorption of nutrients, prevent food intake, produce nutrient losses or increase metabolic requirements (Stephensen, 1999). In particular, I compute the average number of times the infant had feeding problems at baseline or

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and second year of life, and in a second specification over 6-month periods. The shortest periods produce less precise estimates because they require an increase number of IV, and that also apply to my analysis.

[13]I am thankful to Linda Adair who provided me with the caloric intake computed by using the Food Composition Table owned by the Food and Nutrition Research Institute in the Philippines.

[14]I combine two questions: "Was breast milk given to infant yesterday?" and "Was breast milk fed to infant seven days ago?". The child is considered breastfed if the answer is yes to at least one of the questions.

experienced diarrhea episodes in his/her first and second year of life. For simplicity I will refer to these infant diseases as diarrhea episodes.[15]

3.2 Inputs during pre-puberty and puberty

The data collected for older children go from age 8 to age 22. Age 8 can be considered both pre-puberty age or late childhood age. For simplicity, I will refer to it as pre-puberty age.

The nutrition input considered during pre-puberty and puberty is *caloric intake*. The CLHNS data contains 24-hour dietary recalls in 1994, 1998, 2002 and 2005 for which the caloric intake has been computed. During the 1991-92 survey, the child's intake is based on a quantitative food frequency questionnaire, with items derived from a list based on 24-hour food recalls from the mother in the sample. The waves are not evenly spaced but, in the empirical specification, I control for the child's age at the interview and age squared.

I distinguish between *diseases* during infancy and later because they have a different impact on a person, depending on age. To identify the diseases during pre-puberty and puberty I match the historical information in the data about the child's diseases with the diseases listed by Silventoinen (2003) that have been found to negatively affect height. To do this, I refer to the International Statistical Classification of Diseases and Related Health Problems of the World Health Organization.[16] I consider only diseases that might have had a strong impact on the child's health

[15] During the baseline there is a question: "What are the infant's health problems affecting feeding?", and I indicate as 1 if the infant has at least one the problems. In every wave from 1 to 12 there is a yes/no question: "Has the infant had diarrhea during the past seven days?".

[16] The version used is 2007. For details, go to www.who.int/classifications/en/.

and for which the child was hospitalised. Some of these diseases are chronic diseases, characterized by long duration and generally slow progression. It could be that other reported illnesses are temporary or do not strongly affect height. In particular, I distinguish the following groups of diseases: certain infectious and parasitic diseases (e.g., TB, polio, dengue, measles); endocrine, nutritional and metabolic diseases (e.g., diabetes); diseases of the respiratory system (e.g., pneumonia, asthma, weak lungs, tonsillitis); diseases of the digestive system (e.g., ulcers); and congenital malformations, deformations and chromosomal abnormalities (e.g., heart disease). Given that the data contain the list of diseases for which the child was hospitalized since the previous interview, I consider the average number of diseases experienced between the two waves.[17]

It is important to note that the diseases reported when the child was 8 years old include all the illnesses for which the child was hospitalized between age 2 and 8. Therefore, the diseases experienced during the childhood period are not missing. It is true that nutrition during childhood is missing as well as the anthropometric measures, however growth during childhood is a relative stable process and the child follows the trajectory attained previously. Linear growth within the first 2 years of life generally decelerates, but then remains relatively constant though out childhood until the onset of the pubertal growth spurt (Rogol et al., 2000). Shrimpton et al. (2001) use 39 nationally representative datasets from surveys in developing countries on children younger than 60 months and find that anthropometric gaps are largely stable after 2 years of age.

[17]For each child, I consider the time distance in years between the waves because they are not evenly spaced.

Due to the different growth patterns of boys and girls, I estimate the production function by gender.[18] The age at pubic hair growth indicates the beginning of the male puberty, and its median age in the data is 16. The age of menarche instead indicates an advanced stage of the female puberty, and its median age reported in the data is 13. However, the data show that girls continue to grow in the following years (the highest growth velocity is between age 8 and 11, and age 11 and 15).

I also group the last waves because similar both in terms of height and inputs and I consider the data up to when the final height is measured. In particular, I compute the average inputs between waves 16 and 17 for the boys, and between waves 15, 16 and 17 for the girls. If, for example, the final height of a girl is measured at the wave 16, then the inputs are the average inputs between waves 15 and 16, while wave 17 is discarded.[19]

Table 2 reports descriptive statistics for the main variables, by gender and age. The table reports also some other inputs that affect the child's development: genetic and environmental inputs as well as inputs from conception to birth. A proxy for the genetic inputs is *mother's height*.[20] I assume that the rest of the genetic impact is

[18] At birth the typical boy grows faster than the typical girl, but the velocities become equal around 7 months and then girls grow faster until age 4. There are no differences until they reach adolescence. The typical girl is slightly shorter than the typical boy at all ages until adolescence. She is taller during her adolescence spurt because it takes place two years before the male spurt (Tanner, 1990).

[19] The average male height at wave 16 is 162.59 cm (sd 5.90), and at wave 17 is 163.09 cm (sd 5.83). The average female height at waves 15, 16 and 17 is respectively 149.02 cm (sd 5.53), 150.06 (sd 5.45) and 151.17 (sd 5.46). The average male caloric intake at wave 16 is 2106 kcal (sd 978.66) and 2197 kcal (sd 960.67) at wave 17. The average female caloric intake at waves 15, 16 and 17 is respectively 1285 (sd 554.57), 1510 (sd 716.11) and 1544 kcal (sd 744.03). The average male diseases reported at wave 16 and 17 is 0.11 (sd 0.24) and 0.01 (sd 0.07). The average female diseases reported at waves 15, 16 and 17 is respectively 0.06 (sd 0.16), 0.09 (sd 0.18), 0.01 (sd 0.06).

[20] Many medical papers suggest that approximately about 60 to 80 percent of height variation in a population depends on genetic factors, but it is not clear what is the underlying process (see, e.g.,

captured by the individual's biological endowment included in the model. It represents the genetic inheritance and gene-environment interactions that are unobserved factors (Case and Paxson, 2008). An extra variable that captures the environmental inputs is the *location* of the household, and in particular the percentage of time the child has lived in a urban area from conception to maturity. Moreover, table 2 shows descriptive statistics of inputs from conception to birth: the infant's *birth weight*, the *duration of the gestation* (a categorical variable indicating whether the child had normal weight and normal term, low birth weight for his gestational age or simply pre-term but with normal weight for his gestational age), and the *birth order*.[21] Both the inputs from conception to birth and the genetic and environmental inputs are time invariant variables that are not identified by the fixed effect estimators. Table 2 show that there are no relevant differences between boys and girls at birth. The birthweight is on average about 3 kg, 88% of the pregnancies have normal length and the birth order is 2.5 for the girls and 2.6 for the boys. The percentage of time spent in a urban location during the entire life is about 75%. During the first year of life the children are breastfed for most of the time, about 75% for the boys, and 77% for the girls, while there is a decrease in the second year to 38% approximately. The average caloric intake is slightly higher for the boys during infancy, and it in-

Ginsburg et al., 1998; Silventoinen, 2003) nor is the relationship between genetics and environmental factors clear. The data do not contain father's height.

[21]Many researchers suggest that growth *in utero* may play an important role in determining health in adult life (Barker, 1998). The importance of the birth weight is well known and there is a huge literature about it in medicine as well as in economics (e.g., Rosenzweig and Schultz (1983); Behrman and Rosenzweig (2004)). The problems of prematurity are very similar to those of low birth weight. Birth order has also been found to be a significant and independent predictor of adult height (Steckel, 1995). First-born children are, during childhood, taller than children born later, since they have had a period in which they were alone. These inputs from conception to birth are not exactly inputs, but the results of pre-birth inputs that are not available (e.g., birth weight).

creases systematically over time reaching on average 2140 kcal for the boys at the end of their maturation period, and 1420 kcal for the girls. The average times the infant experienced diarrhea are 0.65 in the first year for the boys, and 0.61 for the girls. The diarrhea episodes increase on average to 0.92 in the second year of life for the boys and 0.78 for the girls. Between age 2 and 8 both boys and girls are sick approximately 0.10 times, while between age 8 and 11 only about 0.015 times. Between age 11 and 15 the boys are sick 0.04 times, while between age 11 and the age at final height for girls, the average number of diseases is 0.06 and about 0.08 for the boys between age 15 and the age at final height.

Insert table 2 here.

3.3 Instrumental variables

Tables 7-8 in the Appendix report the descriptive statistics of the IV used in each model.[22] The instruments must be correlated with all or one of the endogenous

[22]Some of the IV used in this paper have been used by other scholars (see for example, Cebu-Study-Team, 1992; Glewwe and King, 2001; Liu et al., 2009; Ugaz and Zanolini, 2011). In particular, Cebu-Study-Team (1992) use the same data to estimate infants health production function and they analyze four different outcomes: gestational age, weight, diarrhea and respiratory infection. They focus only on the first year of life. They use a "value-added" specification, thus, all the past inputs collapse in the past outcome measure. An instrumental variables approach is used to find the effects of the contemporaneous endogenous inputs (e.g., birth weight, gestational age, diarrhea, and few more). Liu, Mroz, and Adair (2009) also estimate health production function using the CLHNS data and consider children in the first two years of life. They estimate an empirical model that includes parents' demand equations and the child's health production functions. Their analysis is based on a dynamic model of parental investments. They jointly estimate four health outcomes: weight, height, incidence of diarrhea and incidence of severe respiratory infections. They also use a "value-added" specification. The endogenous inputs are breast feeding choices, caloric intake for supplement food, prenatal care, mother's working and preventive health care. They consider diarrhea and respiratory infections as health outcomes, and not as inputs in the height production function. Since I consider only height as an outcome and diseases as relevant inputs, my model is not directly comparable with Liu, Mroz, and Adair's (2009) model.

variables (breast milk, caloric intake, disease/diarrhea), but uncorrelated with height. The instruments are time-variant variables computed at the time of each interview. For the infants the IV are averaged over year 1 and year 2. As well as for the inputs, the IV are averaged over the final waves (16 and 17 for boys, or 15, 16 and 17 for the girls) until when the final height is measured.

The variables used are local prices of the main food items (e.g., egg, banana, corn, rice, cooking oil, salt, formula, powder milk, evaporated milk, kerosene),[23] village or barangay characteristics (e.g., elevation, density, existence of dirty roads, health facilities, electricity), and household's characteristics averaged over the same village of current residence[24] (e.g., existence of toilet, garbage, drinking water, piped water, electricity, refrigerator, closeness to a private doctor or midwife, number of houses within 50 meter to the child's house, minutes walk to the nearest food market and to the nearest infant store, distance to the nearest vehicular road, minutes walk to the nearest health facility).

I also include the elevation of the village and a rainfall variable, in particular, if each wave is collected during the rainy or dry season. Cebu was affected by different typhoons at the time of the survey. Ugaz and Zanolini (2011) use the CLHNS data to investigate whether exogenous weather shocks caused by the typhoons had an impact on children's anthropometric outcomes later in life. They look at infants and at the effects of typhoons during the pregnancy and right after birth. I also add as IV the distance in time between the timing of the typhoons and the date of

[23]I thank the National Statistics Office of the Philippines, which provided me with the CPI and inflation rates used to deflate the prices.

[24]To address the potential endogeneity of the household's characteristics, I take their average across the village of residence.

the interviews. This indicates the exposition time to the typhoons. I consider four main typhoons that hit Cebu in different years: Nitang (1/9/84), Ruping (10/11/90), Puring (26/12/93) and Nanang (6/11/01). Nitang was a particularly strong typhoon that had long-lasting impact on people's lives. Since diseases at age 8 reflect diseases experienced between age 2 (year 1985/86) and age 8 (year 1991) I use the distance in months between Nitang and age 8 as IV for the inputs applied at age 8.

Food prices and accessibility to stores and markets are correlated with the food consumption. Many instrumental variables capture sanitation facilities that as well as rainy season and extreme weather conditions, such as typhoons, are associated with problems of malnutrition and water borne diseases (see for examples, Humphrey, 2009; Ugaz and Zanolini, 2011; Spears, 2013).

4 Empirical results

The empirical results are shown in Tables 3-6. The tables report both the FE and IVFE estimates for each model. In the IVFE specifications I consider both nutrition and diseases as endogenous inputs. The estimation of each change in height allows to derive the effect of all the inputs. In particular, I estimate the following equations to identify all the β's contained in model (1):

$$\begin{aligned}
\Delta_{iF}^{boys} &= H_{iF} - H_{i15} = X_{iF}\beta_F + \epsilon_{iF} - \epsilon_{i15} \\
\Delta_{i15}^{boys} &= H_{i15} - H_{i11} = X_{i15}\beta_{15} + \epsilon_{i15} - \epsilon_{i11} \\
\Delta_{iF}^{girls} &= H_{iF} - H_{i11} = X_{iF}\beta_F + \epsilon_{iF} - \epsilon_{i11} \\
\Delta_{i11} &= H_{i11} - H_{i8} = X_{i11}\beta_{11} + \epsilon_{i11} - \epsilon_{i8} \\
\Delta_{i8} &= H_{i8} - H_{i2} = X_{i8}\beta_8 + \epsilon_{i8} - \epsilon_{i2} \\
\Delta_{i2} &= H_{i2} - H_{i1} = X_{i2}\beta_2 + \epsilon_{i2} - \epsilon_{i1} \\
\Delta_{i1} &= H_{i1} - H_{i0} = X_{i1}\beta_1 + \epsilon_{i1} - \epsilon_{i0}
\end{aligned}$$

Insert table 3 here.

Insert table 4 here.

Insert table 5 here.

Insert table 6 here.

Tables 3-6 report also few tests on the quality of the instruments used. In all the models the under identification test (LM test) rejects the null hypothesis indicating that the model is identified and the excluded instruments are relevant and correlated with the endogenous variables. The estimates also satisfy the over identification test (Hansen's J statistic) where the null hypothesis is never rejected, meaning that the instruments are valid. The choice of the IV has been made following redundancy tests and avoiding the presence of instruments highly correlated. Overall, the IVs seem strong, and the IVFE estimates present the expected signs. Tables 9-14 in Appendix report the first stage regression results for each endogenous variable in each model.

The FE provide evidence on the effect of exogenous input variables on height. The IVFE instead allow a causal interpretation of the effects of nutrition and diseases on height. The main difference between FE and IVFE results is the magnitude of the diseases coefficients. In most of the models the effect is negative and larger in the IVFE specification than in the FE.

I mainly focus on the IVFE results that address the endogeneity problem. The effects of the different inputs vary according to the age of the child, but the magnitude and timing is similar between boys and girls. The highest negative variation in height is due to diseases experienced both in early life and during the final stage of growth and this applies to both boys and girls. In particular, once controlled for endogeneity, if a boy is hospitalized because of severe disease during puberty, this causes a reduction of the final height of about 20 cm, while in a girl the effect is much larger, 45 cm. It is important to notice that these coefficients present large confidence intervals, indicating that the estimates might be imprecise. However, the coefficients signs are in line to what is expected. Puberty poses a significant caloric and metabolic burden on the adolescent body and this might destabilize chronic illnesses (Suris et al., 2004).

Nutrition is relevant during the pre-puberty years both for boys and girls (inputs at age 11).[25] Once controlled for endogeneity, if caloric intake increases by 100 kcal at age 11 then height increases in boys by 0.229 cm, and in girls by 0.118 cm. The late childhood or early pre-puberty inputs (inputs at age 8) do not seem to influence

[25]Some girls at age 11 are probably already into the puberty stage.

height. In fact, with the IVFE estimates, the nutrition impact disappears for both boys and girls. Also the diseases reported at age 8 that cover the entire childhood period do not result to be statistically significant.

As for infancy, the inputs applied in the second year of life are significant and larger than the ones applied in the first year. This confirms the results found by Glewwe and King (2001) that using the same data underline the relevance of malnutrition on cognitive development in the second year of life. Once controlled for endogeneity, the importance of nutrition, both breast feeding and caloric intake, vanishes, except at age 2 for boys. The negative effect of diarrhea, instead, increases using the IVFE and remains statistically significant.

In particular, in a 2 years old boy an increase of the caloric intake by 100 kcal results in an increase in height by 0.415 cm and by 3.188 cm if they boy is breastfed. Diarrhea has always a significant and negative impact on infants' height. Experiencing an extra episode of diarrhea in the second year of life, reduces the heigh of a boy by 1.88 cm, and the heigh of a girl by 3.13 cm. If I consider girls, the diarrhea has a strong and negative effect also when experienced in the first year of life, where an increase by one of the diarrhea episodes decreases height by 2 cm.

These results show that growth in infancy and later in the puberty years turn out to be critical stages in the process of height formation.

5 Robustness

5.1 Omitted variables bias

To account for the omitted variables bias, I estimate a *hybrid production function* that includes in the empirical specification (both IV and IVFE) the annual household income in pesos.

In general, the hybrid health production functions are production functions that contain some of the health inputs and the determinants of the other non-available inputs. In this case the health outcome is height, therefore, I estimate the height production functions.

I test the possibility of omitted variables bias by looking at the coefficients of household income in the hybrid production functions. The hybrid production functions are reported in the Appendix, on Tables 15-18. If I consider the IVFE specification, the effect of income is significantly different from zero in the model where the dependent variable is the change between the final height and height at age 15 for the boys, but the effect is negligible. It is also positive and statistically significant for boys during infancy, where an increase of income in the first year of life of the child by 1000 pesos increases height by 0.006 cm, so also a really small effect. Once controlled for endogeneity, the effect of family income is never statistically significant for the girls at any age. Overall, a comparison of Tables 3-6 and Tables 15-18 shows that the estimated input effects are very similar across the nonhybrid and hybrid specifications.

The standard deviation of the income variable is quite high (Table 2), and it is likely that its inclusion does not address satisfactorily the omitted variables problem. Moreover, once income is included, the hybrid effect of the inputs on height is generally a biased estimate of the true technical relationship (other inputs held constant) embodied in the health production function (Rosenzweig and Schultz, 1983).

5.2 Sample selection bias due to attrition

The last wave of the data contains 1888 people (993 males and 895 females, Table 1). Between the baseline and the last wave around 38.7 percent of the children are lost, 18 percent before the age of 2. This high attrition is common in long-term longitudinal studies and in data that come from developing countries. The highest attrition rate is between wave 12 and 13, that is, between infancy and pre-puberty. From wave 12 conducted in 1985-86 and wave 13 conducted in 1991-92 there are approximately 6-7 years of no data.

The two main reasons for attrition are death and migration. Two hundred and twenty-five (7.3 percent of the sample) children die: 167 (5.4 percent) in the first 2 years of life, 44 between the ages of 2 and 8, 14 children die during adolescence. In total 129 boys and 96 girls die. The remaining 31 percent are mainly lost because of migration.

It seems that the people who died tended to be shorter and in poor health. Unfortunately, there are not plausible exclusion restrictions that could be used to test and correct the selection on unobservables that determine death. Hence, given the rather low percentage of children who died, I keep them in the sample. Attrition due to mortality is claimed not to represent a big problem because only a small proportion of children in the poorest health conditions are lost (this is also claimed by Eckhardt et al., 2005, who use the same data). If a selection mechanism is in place so that only the healthiest survive, then my estimates would be a lower bound of the true effect.

As for migration, Cebu-Study-Team (1992) tested for selectivity of infants and the results show that the omitted variables that influence migration decisions do not coincide with those that determine child health. Older children who moved are in some years slightly healthier than the non attritors. If those who migrate are the better-off in the village, then the effects of nutrition and diseases on height are overestimated. However, the differences in terms of height, diseases and caloric intake, between the movers and the people who stay in the survey, are small and therefore I do not suspect selective migration to be a source of problem.

6 Conclusions

In this paper I study the determinants of height building a height production function from birth to maturity. I consider the cumulative nature of physical development, taking into account the biological inputs that cover the entire process of height formation. I estimate an empirical specification for the height production function where the change in height between two consecutive measurements allow the reduction of the endogenous inputs. I use both FE and IVFE. The IVFE allow the estimation of conditional demand equations for both nutrition and diseases, treated as endogenous inputs.

The results show that the timing of diseases is particularly important. Diarrhea episodes have larger and negative effects on height if experienced in the second year of life. Diseases experienced during puberty have the strongest effects both in boys and girls. Also nutrition plays a role during the pre-puberty years, while in other periods its effect is dominated by the diseases. Nutrition and diseases are closely related given that some adverse health conditions might have occurred because of early malnutrition and infectious load. Moreover chronic conditions measured at puberty have long duration and might have started years before.

The model shows the importance of including past inputs and of studying their effects according to different ages of the children. On the other hand, the results show it is important to know what factors determine a person's height at different growth periods of her life in a poor country, which periods are critical, and which inputs have the strongest impact on growth. In fact, growth during infancy and puberty turn out to be critical stages in the process of height formation. The results of this paper are in line with the increasing literature on the long term effects of early life conditions (Almond and Currie, 2011) and with new studies that reveal the importance of later critical periods (van den Berg et al., 2014). Most importantly the paper shows that critical periods are important because diseases play a major role compared to nutritional intake.

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Figures and tables

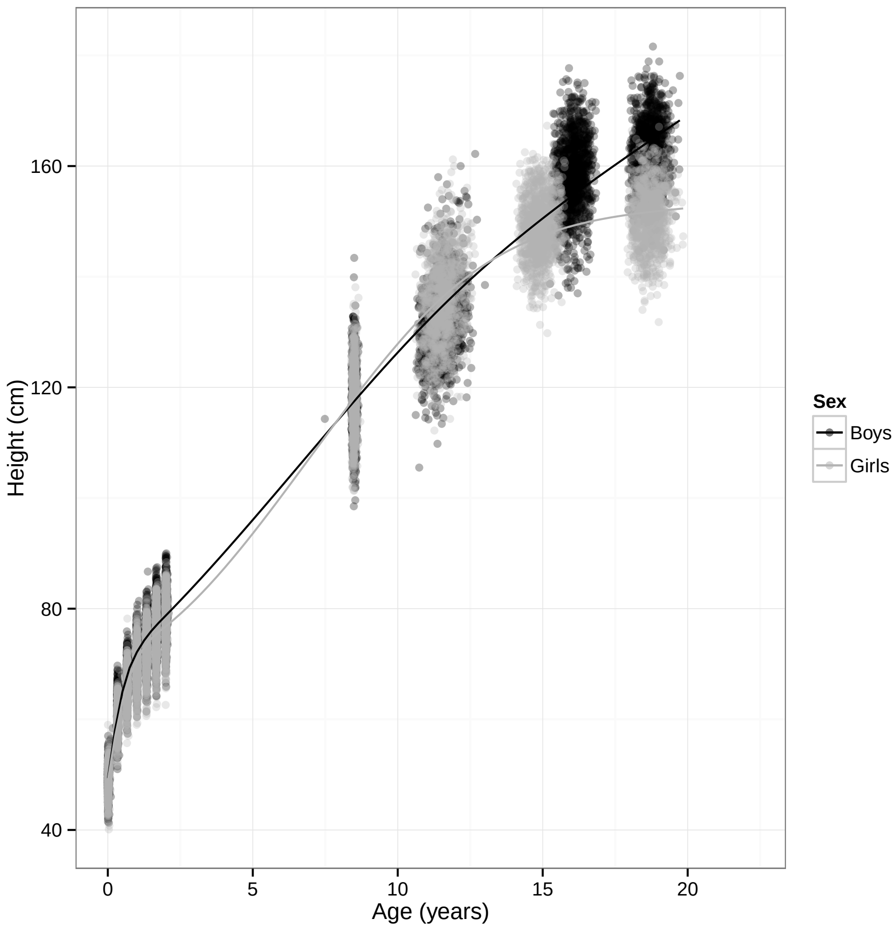

Figure 1: Height distribution by age and gender of the child. The dots correspond to the raw height measurements, while the lines correspond to spline interpolation of the mean height per gender and age of the child.

Table 1: Panel structure and range of ages by gender.

Surveys	Boys			Girls		
	N	Mean age	SD	N	Mean age	SD
Months						
Delivery 1983-4	1632	0	0	1448	0	0
Follow-up n.1	1525	2.051	.152	1353	2.051	.149
Follow-up n.2	1489	4.040	.139	1313	4.052	.170
Follow-up n.3	1439	6.051	.158	1278	6.045	.149
Follow-up n.4	1406	8.037	.126	1259	8.038	.141
Follow-up n.5	1386	10.068	.144	1239	10.068	.160
Follow-up n.6	1367	12.076	.169	1227	12.070	.164
Follow-up n.7	1342	14.072	.164	1207	14.073	.186
Follow-up n.8	1316	16.070	.178	1191	16.063	.171
Follow-up n.9	1310	18.068	.172	1197	18.054	.169
Follow-up n.10	1316	20.078	.190	1182	20.050	.161
Follow-up n.11	1302	22.047	.164	1158	22.041	.162
Follow-up n.12	1288	24.055	.153	1160	24.047	.153
Years						
1991-2 Follow-up n.13	1195	8.500	.051	1069	8.502	.044
1994-5 Follow-up n.14	1142	11.526	.405	1040	11.543	.399
1998-9 Follow-up n.15	1092	16.061	.328	997	14.905	.363
2002 Follow-up n.16	1071	18.697	.332	952	18.701	.350
2005 Follow-up n.17	993	21.467	.297	895	21.453	.312

Table 2: Descriptive statistics of the principal variables

	Birth		Age 1		Age 2		Age 8		Age 11		Age 16		Age final height†	
Boys	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
N	1618		1367		1.288		1192		1138		1087		1074	
Height (cm)	49.46	2.15	71.449	2.883	79.868	3.581	117.738	5.537	132.386	7.039	158.45	6.791	163.23	585.356
Age (years)	.0128	.013	1.006	.014	2.005	.013	8.500	.051	11.525	.404	16.06	.328	20.465	13.618
Breastmilk			.753	.383	.340	.369								
Caloric intake (kcal)			331.450	2.839	670.536	3.286	1506.35	6.003	1257.38	6.121	1914.63	7.804	2140.32	8.787
Diseases/diarrhea			.649	.849	.916	1.055	.105	.146	.014	.073	.043	.104	.0774	.1729
Birthweight* (kg)	3.02	0.45												
Birth order*	2.59	2.46												
Normal pregnancy	88.94%													
Premature&Small	7.53%													
Premature	3.52%													
Mother's height*(cm)	151.58	5.02												
% Urban location*	.75	.42												
Family income (pesos)			93,658	153,084	84,373	130,173	123,699	163,250	141,543	174,592	174,270	172,449	266,714	2,610,128

	Birth		Age 1		Age 2		Age 8		Age 11		Age final height†	
Girls	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
N	1433		1226		1160		1067		1039		1015	
Height (cm)	49.01	2.11	69.923	2.841	78.315	3.630	117.623	5.573	135.335	7.623	151.271	5.480
Age (years)	.012	.013	1.005	.013	2.004	.013	8.502	.044	11.543	.399	19.905	1.965
Breastmilk			.773	.375	.343	.370						
Caloric intake (kcal)			293.536	2.525	607.093	2.950	1353.66	5.060	1140.47	5.149	1419.48	5.398
Diseases/diarrhea			.613	.793	.778	.957	.102	.127	.016	.085	.064	.121
Birthweight* (kg)	2.96	.43										
Birth order*	2.50	2.39										
Normal pregnancy	88.08%											
Premature&Small	7.95%											
Premature	3.97%											
Mother's height*(cm)	151.47	5.03										
% Urban location*	.74	.42										
Family income (pesos)			93,874	21,571	75,976	100,580	121,023	128,718	136,561	157,355	177,755	197,296

[a] * corresponds to time-invariant variables.

[b] † For the boys waves 16 and 17 are combined, for the girls waves 15, 16 and 17 are combined.

Table 3: Boys' height production function during pre-puberty and puberty. Dependent variable: change in height

	Δ_{Height}F		Δ_{Height}16		Δ_{Height}11		Δ_{Height}8	
	FE	IVFE	FE	IVFE	FE	IVFE	FE	IVFE
Caloric intake ageF	-0.0552***	0.0483						
	[0.0109]	[0.0684]						
Diseases age F	0.121	-20.80*						
	[0.487]	[8.560]						
Caloric intake age 16			-0.0208	-0.0113				
			[0.0162]	[0.0636]				
Diseases age 16			-0.740	-1.776				
			[1.316]	[8.120]				
Caloric intake age 11					0.108***	0.229***		
					[0.0162]	[0.0503]		
Diseases age 11					-2.205	-16.15		
					[1.227]	[13.69]		
Caloric intake age 8							0.0825***	0.0435
							[0.0215]	[0.0935]
Diseases age 8							-0.953	9.384
							[0.842]	[8.015]
N	1049	999	1078	779	1128	944	1119	1052
R-sq	0.684	0.343	0.977	0.976	0.954	0.946	0.990	0.988
Underid. test		13.479*		26.057***		18.042*		10.611†
p-value		0.0360		0.0005		0.0118		0.0597
Overid. test		7.371		7.543		5.852		3.945
p-value		0.1945		0.2735		0.4400		0.4135
F test for IV								
Kcal		32.06***		10.44***		28.29***		15.27***
Diseases		4.64***		5.27***		2.40***		2.96**

[a] Every model includes age and age squared.
[b] A change of one unity in caloric intake corresponds to 100 kcal.
[c] Robust standard error in parenthesis.
[d] Signif. codes: (†) if p < .1, (*) if p < .05, (**) if p < .01, (***) if p < .001.
[e] F indicates final height.

Table 4: Boys' height production function during infancy. Dependent variable: change in height

	$\Delta_{Height}2$		$\Delta_{Height}1$	
	FE	IVFE	FE	IVFE
Breastmilk age 2	0.938***	2.773		
	[0.189]	[1.528]		
Caloric intake age 2	0.197***	0.415***		
	[0.0210]	[0.109]		
Diarrhea age 2	-0.278***	-1.878***		
	[0.0540]	[0.404]		
Breastmilk age 1			0.726*	-2.418
			[0.356]	[2.580]
Caloric intake age 1			0.131**	-0.0804
			[0.0451]	[0.285]
Diarrhea age 1			-0.142	-1.080
			[0.0882]	[0.559]
N	1250	941	1359	1300
R-sq	0.944	0.896	0.986	0.983
Underid. test		23.554**		14.920**
p-value		0.0089		0.0049
Overid. test		14.949		3.770
p-value		0.0923		0.2874
F test for IV				
Breastmilk		4.20***		36.91***
Caloric intake		19.64 ***		7.44***
Diarrhea		4.45***		20.22 ***

[a] Every model includes age and age squared.
[b] The kcal is exclusive of breast milk.
[c] A change of one unity in caloric intake corresponds to 100 kcal.
[d] Robust standard error in parenthesis.
[e] Signif. codes: (*) if p < .05, (**) if p < .01, (***) if p < .001.

Table 5: Girls' height production function during pre-puberty and puberty. Dependent variable: change in height

	Δ_{Height}F		Δ_{Height}11		Δ_{Height}8	
	FE	IVFE	FE	IVFE	FE	IVFE
Caloric intake age F	-0.0943**	0.0265				
	[0.0313]	[0.151]				
Diseases age F	-1.491	-45.79*				
	[1.717]	[20.73]				
Caloric intake age 11			0.111***	0.118*		
			[0.0235]	[0.0532]		
Diseases age 11			1.990*	-0.124		
			[0.999]	[9.797]		
Caloric intake age 8					0.126***	-0.0957
					[0.0265]	[0.0936]
Diseases age 8					-0.267	-3.208
					[1.007]	[7.955]
N	1009	998	1028	859	991	813
R-sq	0.898	0.784	0.959	0.957	0.990	0.989
Underid. test		9.861*		18.387*		16.039**
p-value		0.0428		0.0185		0.0067
Overid. test		5.397		7.619		7.697
p-value		0.1449		0.3674		0.1033
F test for IV						
Kcal		37.51***		32.19***		20.84***
Diseases		4.87***		3.35***		2.84**

[a] Every model includes age and age squared.
[b] A change of one unity in caloric intake corresponds to 100 kcal.
[c] Robust standard error in parenthesis.
[d] Signif. codes: (*) if $p < .05$, (**) if $p < .01$, (***) if $p < .001$.
[e] F indicates final height.

Table 6: Girls' height production function during infancy. Dependent variable: change in height

	$\Delta_{Height}2$		$\Delta_{Height}1$	
	FE	IVFE	FE	IVFE
Breastmilk age 2	1.066***	1.062		
	[0.206]	[2.385]		
Caloric intake age 2	0.190***	0.178		
	[0.0264]	[0.168]		
Diarrhea age 2	-0.269***	-3.129***		
	[0.0676]	[0.863]		
Breastmilk age 1			1.144***	3.910
			[0.333]	[4.194]
Caloric intake age 1			0.171***	0.346
			[0.0470]	[0.408]
Diarrhea age 1			-0.280**	-2.031*
			[0.0946]	[0.869]
N	1119	940	1221	1156
R-sq	0.937	0.839	0.985	0.979
Underid. test		20.653***		10.890*
p-value		0.0009		0.0278
Overid. test		6.116		0.393
p-value		0.1906		0.9416
F test for IV				
Breastmilk		4.38***		18.66***
Caloric intake		20.36***		42.20***
Diarrhea		3.9***		3.95***

[a] Every model includes age and age squared.
[b] The kcal is exclusive of breast milk.
[c] A change of one unity in caloric intake corresponds to 100 kcal.
[d] Robust standard error in parenthesis.
[e] Signif. codes: (*) if p < .05, (**) if p < .01, (***) if p < .001.

Appendix

Table 7: Boys. Descriptive statistics of the instrumental variables used.

IV variables	Definitions	N	Mean	SD
Season age F	% of rainy season	1074	.508	.338
Density age F	population density of brgy	1025	13601.9	15094.92
Egg price age F	price of medium size egg	1073	2.991	.280
Dirt road age F	dirt roads in brgy	1025	.371	.483
Refrigerator age F†	% hh in the brgy with refrigerator	1074	.419	.180
N. houses age F†	n. houses within 50 m to the resp house	1074	16.824	4.263
Month after Nanang age F	months after typhoon Nanang	1074	28.956	16.086
Season age 16	% of rainy season	1087	.632	.396
Elevation age 16	brgy's aver. elevation above sea level	883	22.205	44.855
Corn price age 16	price of 1 kg corn	907	16.892	.629
Dirt road age 16	does barangay have dirt roads?	1044	.698	.459
Toilet age 16†	% hh in the brgy with toilet	1087	.776	.267
Electricity age 16†	% hh in the brgy with electricity	1087	.876	.199
Drinking water age 16†	% hh in the brgy with drinnking water	1087	.847	.283
Months after Puring age 16	months after typhoon Puring	1087	70.480	2.253
Season age 11	% of rainy season	1138	.274	.390
Elevation age 11	brgy's aver. elevation above sea level	956	21.463	44.046
Cooking oil price age 11	price of 75cl cooking oil	1133	1.159	.210
Egg price age 11	price of medium size egg	1133	3.472	.266
Salt price age 11	price of 1 kg salt	1132	19.567	23.417
Garbage age 11†	% hh in the brgy with garbage	1138	.388	.316
Refrigerator age 11†	% hh in the brgy with refrigerator	1138	.291	.178
Months after Puring age 11	months after typhoon Puring	1138	16.000	3.493
Egg price age 8	price of medium size egg	1122	4.145	.391
Months after Ruping age 8	months after typhoon Ruping	1192	17.223	3.430
Public health facility age 8	private health facility	1189	3.172	1.655
Time to food market age 8†	mins walk to nearest food market	1192	45.094	48.658
Drinking water age 8†	% hh in the brgy with drinking water	1155	.773	.242
Month after Nitang age 8	months after typhoon Nitang	1192	13.022	4.056
Kerosene price age 2	price of 1 lt of kerosene	1241	3565.12	671.498
Formula price age 2	price of 400 g formula milk	972	11382.2	1095.50
Powder price age 2	price of 350 g powdered milk	1084	8626.37	543.800
Rice price age 2	price of 1 kg rice	1153	2230.08	120.29
Egg price age 2	price of medium size egg	1196	473.714	25.502
Dirt road age 2	does barangay have dirt roads?	1233	.560	.497
Elevation age 2	brgy's aver. elevation above sea level	1241	23.408	51.587
Toilet age 2†	% hh in the brgy with toilet	1288	.662	.293
Distance road age 2†	distance (m) to nearest vehicular road	1282	279.101	516.595
Time to infant store age 2†	mins walk to nearest infant store	1288	16.746	18.421
Private doctor age 2†	private doctor or midwife	1288	.812	.106
Infant food store age 2†	near store selling infant food	1288	.710	.217
Corn price age 1	price of 1 kg corn	1307	1580.57	124.951
Season age 1	% of rainy season	1366	.514	.022
Toilet age 1†	% hh in the brgy with toilet	1366	.672	.288
Time to trad health facility age 1†	mins walk to nearest traditional health facility	1366	22.441	8.260
Infant food store age 1†	near store selling infant food	1366	.709	.212
Month after Nitang age 1	months after typhoon Nitang	1367	1.732	2.253

[a] † indicates household characteristics averaged at village level.

Table 8: Girls. Descriptive statistics of the instrumental variables used.

IV variables	Definitions	N	Mean	SD
Egg price age F	price of medium size egg	1003	3.111	.262
Months after Nanang age F	months after typhoon Nanang	1015	25.246	17.420
Refrigerator age F†	% hh in the brgy with refrigerator	1016	.397	.175
N. houses age F†	n. houses within 50 m to the resp house	1016	17.051	4.222
Toilet age F†	% hh in the brgy with toilet	1016	.792	.241
Elevation age 11	brgy's aver. elevation above sea level	872	21.751	45.394
Cooking oil price age 11	price of 75cl cooking oil	1031	116.337	.198
Corn price age 11	price of 1 kg corn	1030	181.704	1.241
Egg price age 11	price of medium size egg	1031	3.460	.273
Private health facility age 11	private health facility	1031	.770	.573
Garbage age 11†	% hh in the brgy with garbage disposal	1.039	.370	.317
Electricity age 11†	% hh in the brgy with electricity	1.039	.793	.238
Drinking water age 11†	% hh in the brgy with drinking water	1.039	.835	.302
Months after Puring age 11	months after typhoon Puring	1.039	16.269	3.435
Elevation age 8	brgy's aver. elevation above sea level	927	20.888	43.516
Egg price age 8	price of medium size egg	1002	4.148	.413
Electricity age 8†	% hh in the brgy with electricity	1067	.731	.266
Drinking water age 8†	% hh in the brgy with drinking water	1.067	.822	.308
Time to food market age 8†	mins walk to nearest food market	1067	45.116	49.018
N. houses age 8†	n. houses within 50 m to the resp house	1.067	16.769	3.998
Kerosene price age 2	price of 1 lt of kerosene	1115	3556.29	704.747
Banana price age 2	price of 1 banana	1028	117.434	29.065
Powder price age 2	price of 350 g powdered milk	970	8617.65	573.267
Electricity age 2	electricity in the brgy	1113	.912	.283
Piped water age 2†	% brgy with piped water	1160	.842	.279
Distance road age 2†	distance (m) to nearest vehicular road	1156	285.455	531.207
Infant food store age 2†	near store selling infant food	1160	.693	.229
Evaporated price age 1	price of 100 g evaporated milk	1187	833.029	84.663
Banana price age 1	price of 1 banana	1161	130.633	29.254
Distance road age 1†	distance (m) to nearest vehicular road	1222	273.193	514.314
Refrigerator age 1†	% hh in the brgy with refrigerator	1226	.062	.042
Time to infant store age 1†	mins walk to nearest infant store	1226	17.012	18.284
Month after Nitang age 1	months after typhoon Nitang	1226	1.767	2.248

[a] † indicates household characteristics averaged at village level.

Table 9: Boys during pre-puberty and puberty. First-stage estimates.

	Caloric intake age F	Diseases age F		Caloric intake age 15	Diseases age 15
$\Delta_{age} ageF$	-0.484	0.035	$\Delta_{age} age16$	-8.758**	-0.052
	[3.324]	[0.061]		[2.931]	[0.042]
$\Delta_{age^2} ageF$	0.184*	0.00110	$\Delta_{age^2} age16$	0.280**	0.001
	[0.094]	[0.002]		[0.107]	[0.001]
Season age F	2.532*	0.0253	Season age 16	5.080**	0.0231
	[1.188]	[0.028]		[1.754]	[0.023]
Density age F	0.00005	7.12e-08	Elevation age 16	0.019	0.0004
	[0.00003]	[0.0000005]		[0.0204]	[0.0002]
Egg price age F	0.423	-0.018	Corn price age 16	-0.978	-0.0170
	[1.017]	[0.018]		[0.673]	[0.010]
Dirt road age F	0.746	-0.023	Dirt road age 16	-0.0742	0.0345***
	[0.783]	[0.013]		[0.764]	[0.010]
Refrigerator age F†	5.899**	0.025	Toilet age 16†	6.122***	0.070**
	[1.858]	[0.0287]		[1.649]	[0.021]
N. houses age F†	0.232**	0.0008	Electricity age 16†	9.156*	-0.127*
	[0.072]	[0.001]		[4.203]	[0.064]
Month after Nanang age F	-0.564***	-0.008**	Drinking water age 16†	-3.635	0.046
	[0.145]	[0.002]		[2.484]	[0.026]
			Months after Puring age 16	0.380*	0.005*
				[0.175]	[0.002]
N	999	999	N	779	779
R-sq	0.869	0.200	R-sq	0.872	0.172

[a] † indicates household characteristics averaged at village level.

Table 10: Boys during pre-puberty and puberty. First-stage estimates.

	Caloric intake age 11	Diseases age 11		Caloric intake age 8	Diseases age 8
$\Delta_{age}age11$	9.238	-0.0846	$\Delta_{age}age8$	-3.017	-0.537
	[6.111]	[0.072]		[12.75]	[0.318]
$\Delta_{age^2}age11$	-0.339	0.004	$\Delta_{age^2}age8$	0.665	0.054
	[0.275]	[0.003]		[1.242]	[0.031]
Season age 11	-0.002	0.007	Egg price 8	-1.791***	-0.004
	[0.675]	[0.007]		[0.538]	[0.011]
Elevation age 11	-0.0104*	-0.00002	Months after Ruping age 8	-0.849	-0.043*
	[0.004]	[0.00004]		[0.744]	[0.018]
Cooking oil price age 11	2.377	0.0002	Public health fac age 8	0.431***	0.006
	[1.637]	[0.032]		[0.122]	[0.003]
Egg price age 11	0.093	0.0151	Time to food market age 8†	-0.025***	0.00006
	[0.818]	[0.010]		[0.006]	[0.0002]
Salt price age 11	0.002	-0.00003	Drinking water age 8†	1.565	0.036
	[0.008]	[0.0001]		[0.913]	[0.021]
Garbage age 11†	4.913***	-0.015	Month after Nitang age 8	0.726	0.044*
	[0.885]	[0.009]		[0.751]	[0.018]
Refrigerator age 11†	8.922***	0.042			
	[1.659]	[0.030]			
Months after Puring age 11	-0.139	-0.003***			
	[0.091]	[0.001]			
N	944	944	N	1052	1052
R-sq	0.843	0.048	R-sq	0.880	0.349

[a] † indicates household characteristics averaged at village level.

Table 11: Boys during infancy. First-stage estimates.

	Breastmilk age 2	Caloric intake age 2	Diarrhea age 2		Breastmilk age 1	Caloric intake age 1	Diarrhea age 1
$\Delta_{age}2$	1.432 [1.772]	-39.21* [16.54]	-3.870 [5.396]	$\Delta_{age}age1$	1.968** [0.732]	-4.871 [4.890]	-0.810 [1.241]
$\Delta_{age^2}2$	-0.649 [0.554]	12.27* [5.068]	1.377 [1.739]	$\Delta_{age^2}age1$	-0.875 [0.609]	3.544 [4.379]	0.114 [1.055]
Kerosene price age 2	0.000004 [0.00003]	-0.0004 [0.0003]	0.0003** [0.0001]	Corn price age 1	0.0001 [0.00009]	-0.0006 [0.0007]	-0.0008*** [0.0002]
Formula price age 2	0.0000005 [0.00001]	0.00008 [0.00012]	0.00009* [0.00004]	Season age 1	-0.860 [0.601]	8.057* [3.914]	5.236*** [1.315]
Powder price age 2	0.00009** [0.00003]	0.0006 [0.0003]	-0.0002 [0.0001]	Toilet age 1†	-0.220*** [0.0501]	2.664*** [0.352]	-0.0155 [0.130]
Rice price age 2	0.0002 [0.0002]	0.0019 [0.002]	-0.0006 [0.0006]	Time to trad health fac age 1†	0.0025* [0.001]	-0.0199* [0.008]	-0.0058* [0.003]
Egg price age 2	-0.00001 [0.0006]	-0.0157*** [0.005]	0.00218 [0.002]	Infant store age 1†	-0.033 [0.071]	0.153 [0.473]	-0.108 [0.171]
Dirt road age 2	-0.075* [0.033]	-0.037 [0.301]	-0.175 [0.099]	Month after Nitang age 1	0.015*** [0.005]	-0.011 [0.035]	0.047*** [0.011]
Elevation age 2	0.002 [0.002]	-0.029 [0.019]	-0.029*** [0.007]				
Toilet age 2†	-0.293** [0.104]	3.269*** [0.887]	0.0253 [0.304]				
Distance road age 2†	-0.00035** [0.0001]	-0.004** [0.001]	-0.0001 [0.0004]				
Time to infant store age 2†	0.00307 [0.005]	0.140** [0.044]	0.0467* [0.019]				
Priv doctor age 2†	-0.131 [0.188]	4.567** [1.653]	-0.548 [0.601]				
Infant food store age 2†	0.0154 [0.132]	1.766 [1.140]	1.322* [0.517]				
N	941	941	941	N	1300	1300	1300
R-sq	0.461	0.858	0.473	R-sq	0.812	0.622	0.397

[a] † indicates household characteristics averaged at village level.

Table 12: Girls during puberty. First-stage estimates.

	Caloric intake age F	Diseases age F
$\Delta_{age} ageF$	0.712	-0.005
	[0.905]	[0.022]
$\Delta_{age^2} ageF$	-0.006	0.0005
	[0.029]	[0.0007]
Egg price age F	1.095***	-0.00786
	[0.299]	[0.006]
Months after Nanang age F	-0.019	-0.002**
	[0.032]	[0.0007]
Refrigerator age F†	4.753***	0.027
	[1.182]	[0.0230]
N. houses age F†	0.194***	0.002*
	[0.049]	[0.001]
Toilet age F†	2.245*	-0.012
	[1.010]	[0.023]
N	998	998
R-sq	0.891	0.259

[a] † indicates household characteristics averaged at village level.

Table 13: Girls during pre-puberty. First-stage estimates.

	Caloric intake age11	Diseases age 11 age 11		Caloric intake age8	Diseases age 8
$\Delta_{age}age11$	-12.90	-0.134	$\Delta_{age}age8$	11.21*	0.032
	[7.994]	[0.131]		[5.617]	[0.147]
$\Delta_{age^2}age11$	0.609	0.00501	$\Delta_{age^2}age8$	-0.948	-0.003
	[0.350]	[0.006]		[0.532]	[0.0140]
Elevation age 11	-0.0139**	0.00003	Elevation age 8	0.046***	0.0002
	[0.005]	[0.00006]		[0.012]	[0.0003]
Cooking oil price age 11	4.536*	-0.0129	Egg price age 8	-0.382	0.025*
	[1.798]	[0.038]		[0.417]	[0.012]
Corn price age 11	0.569**	-0.006	Electricity age 8†	0.210	0.096*
	[0.208]	[0.004]		[1.433]	[0.038]
Egg price age 11	-0.629	0.049**	Drinking water age 8†	1.556*	-0.075**
	[0.874]	[0.0188]		[0.735]	[0.023]
Priv health facility age 11	1.046**	0.00196	Time to food market age 8†	-0.0292	-0.0006
	[0.335]	[0.009]		[0.015]	[0.0004]
Garbage age 11†	4.634***	0.006	N. houses age 8†	0.343**	-0.002
	[0.805]	[0.015]		[0.104]	[0.003]
Electricity age 11†	3.533**	0.109**			
	[1.321]	[0.0330]			
Drinking water age 11†	-0.193	-0.069**			
	[1.047]	[0.0215]			
Months after Puring age 11	-0.285***	0.002			
	[0.0843]	[0.00165]			
N	859	859	N	813	813
R-sq	0.864	0.056	R-sq	0.904	0.405

[a] † indicates household characteristics averaged at village level.

Table 14: Girls during infancy. First-stage estimates.

	Breastmilk age 2	Caloric intake age 2	Diarrhea age 2		Breastmilk age 1	Caloric intake age 1	Diarrhea age 1
$\Delta_{age}age2$	3.320	-53.35***	-1.760	$\Delta_{age}age1$	1.672*	-2.722	1.175
	[2.090]	[16.10]	[5.918]		[0.722]	[4.869]	[1.355]
$\Delta_{age^2}age2$	-0.981	19.41***	1.075	$\Delta_{age^2}age1$	-1.126	6.548	-0.247
	[0.702]	[5.332]	[1.970]		[0.681]	[4.545]	[1.274]
Kerosene price age 2	0.00004	-0.001***	0.0002*	Evaporated price age 1	0.0004*	-0.0029*	-0.0007
	[0.00003]	[0.0002]	[0.0001]		[0.0002]	[0.001]	[0.0004]
Banana price age 2	-0.0007	0.009*	-0.0009	Banana price age 1	-0.0003	0.004	0.002*
	[0.0005]	[0.004]	[0.001]		[0.0004]	[0.002]	[0.0009]
Powder price age 2	0.00002	0.0001	-0.0002*	Distance road age 1†	0.0001***	-0.0009**	-0.0003*
	[0.00003]	[0.0002]	[0.00006]		[0.00005]	[0.0003]	[0.0001]
Electricity age 2	-0.128	0.641	0.469	Refrigerator age 1†	-0.893*	12.12***	-0.897
	[0.0902]	[0.493]	[0.249]		[0.351]	[2.218]	[0.728]
Piped water age 2†	-0.313**	1.538*	-0.687**	Time to infant store age 1†	-0.003*	0.015	0.006
	[0.0976]	[0.645]	[0.232]		[0.001]	[0.009]	[0.003]
Distance road age 2†	-0.00002	-0.003***	-0.0006**	Month after Nitang age 1	0.002	0.058	0.040***
	[0.0001]	[0.0007]	[0.0002]		[0.005]	[0.034]	[0.011]
Infant food store age 2†	0.192*	1.021	0.602*				
	[0.094]	[0.640]	[0.240]				
N	940	940	940	N	1156	1156	1156
R-sq	0.467	0.845	0.422	R-sq	0.820	0.621	0.389

[a] † indicates household characteristics averaged at village level.

Table 15: Boys' hybrid height production function during pre-puberty and puberty. Dependent variable: change in height

	Δ_{Height}F		Δ_{Height}16		Δ_{Height}11		Δ_{Height}8	
	FE	IVFE	FE	IVFE	FE	IVFE	FE	IVFE
Family income age F	0.00008***	0.00006**						
	[0.00001]	[0.00002]						
Caloric intake age F	-0.0548***	0.050						
	[0.011]	[0.0687]						
Diseases age F	0.141	-21.14*						
	[0.487]	[8.582]						
Family income age 16			-0.0003	-0.00003				
			[0.0007]	[0.001]				
Caloric intake age 16			-0.019	-0.009				
			[0.016]	[0.072]				
Diseases age 16			-0.722	-1.815				
			[1.315]	[8.124]				
Family income age 11					0.001	0.0009		
					[0.0007]	[0.001]		
Caloric intake age 11					0.100***	0.214***		
					[0.017]	[0.057]		
Diseases age 11					-2.279	-15.69		
					[1.217]	[13.13]		
Family income age 8							0.0009	0.0008
							[0.0006]	[0.0008]
Caloric intake age 8							0.0776***	0.036
							[0.022]	[0.099]
Diseases age 8							-0.969	9.222
							[0.842]	[7.966]
N	1049	999	1078	779	1128	944	1118	1051
R-sq	0.685	0.332	0.977	0.976	0.955	0.947	0.99	0.988

[a] Every model includes age and age squared.
[b] A change of one unity in caloric intake corresponds to 100 kcal.
[c] A change of one unity in income corresponds to 1000 pesos.
[d] Robust standard error in parenthesis.
[e] Signif. codes: (†) if p < .1, (*) if p < .05, (**) if p < .01, (***) if p < .001.

Table 16: Boys' hybrid height production function during infancy. Dependent variable: change in height

	$\Delta_{Height}2$		$\Delta_{Height}1$	
	FE	IVFE	FE	IVFE
Family income age 2	0.001*	-0.001		
	[0.0004]	[0.001]		
Breastmilk age 2	0.905***	2.813		
	[0.197]	[1.717]		
Caloric intake age 2	0.169***	0.454***		
	[0.023]	[0.133]		
Diarrhea age 2	-0.270***	-1.995***		
	[0.057]	[0.463]		
Family income age 1			0.002***	0.001*
			[0.0005]	[0.0006]
Breastmilk age 1			0.426	-1.347
			[0.399]	[2.818]
Caloric intake age 1			0.0624	0.0537
			[0.0493]	[0.292]
Diarrhea age 1			-0.076	-1.041
			[0.097]	[0.575]
N	1106	822	1095	1045
R-sq	0.947	0.89	0.986	0.984

[a] Every model includes age and age squared.
[b] The kcal is exclusive of breast milk.
[c] A change of one unity in caloric intake corresponds to 100 kcal.
[d] A change of one unity in income corresponds to 1000 pesos.
[e] Robust standard error in parenthesis.
[f] Signif. codes: (*) if p < .05, (**) if p < .01, (***) if p < .001.

Table 17: Girls' hybrid height production function during pre-puberty and puberty. Dependent variable: change in height

	Δ_{Height}F		Δ_{Height}11		Δ_{Height}8	
	FE	IVFE	FE	IVFE	FE	IVFE
Family income age F	-0.003*	-0.001				
	[0.00105]	[0.00144]				
Caloric intake age F	-0.072*	0.047				
	[0.0324]	[0.152]				
Diseases age F	-1.162	-44.30*				
	[1.691]	[20.77]				
Family income age 11			0.001	0.001		
			[0.0009]	[0.001]		
Caloric intake age 11			0.104***	0.105		
			[0.0240]	[0.0571]		
Diseases age 11			1.937	-0.322		
			[1.007]	[9.793]		
Family income age 8					0.003**	0.006**
					[0.001]	[0.002]
Caloric intake age 8					0.101***	-0.184
					[0.0271]	[0.107]
Diseases age 8					-0.388	-8.12
					[0.999]	[8.607]
N	1008	997	1028	859	991	813
R-sq	0.899	0.821	0.96	0.957	0.99	0.988

[a] Every model includes age and age squared.
[b] A change of one unity in caloric intake corresponds to 100 kcal.
[c] A change of one unity in income corresponds to 1000 pesos.
[d] Robust standard error in parenthesis.
[e] Signif. codes: (*) if p < .05, (**) if p < .01, (***) if p < .001.

Table 18: Girls' hybrid height production function during infancy. Dependent variable: change in height

	$\Delta_{Height}2$		$\Delta_{Height}1$	
	FE	IVFE	FE	IVFE
Family income age 2	0.0002	0.0002		
	[0.000499]	[0.00148]		
Breastmilk age 2	1.038***	0.396		
	[0.224]	[2.463]		
Caloric intake age 2	0.177***	0.129		
	[0.0294]	[0.208]		
Diarrhea age 2	-0.242***	-3.120**		
	[0.0727]	[1.007]		
Family income y1			0.0007*	0.001
			[0.0003]	[0.001]
Breastmilk age 1			1.037**	4.063
			[0.365]	[5.298]
Caloric intake age 1			0.138**	0.407
			[0.0532]	[0.441]
Diarrhea age 1			-0.257*	-2.473*
			[0.102]	[1.045]
N	989	822	1003	954
R-sq	0.937	0.837	0.985	0.977

[a] Every model includes age and age squared.
[b] The kcal is exclusive of breast milk.
[c] A change of one unity in caloric intake corresponds to 100 kcal.
[d] A change of one unity in income corresponds to 1000 pesos.
[e] Robust standard error in parenthesis.
[f] Signif. codes: (*) if $p < .05$, (**) if $p < .01$, (***) if $p < .001$.

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