Is there Catch-Up Growth? Evidence from Three Continents

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Abstract

The ability to correct deficiencies in early childhood malnutrition, what is known as catch-up growth, has wide spread consequences for economic and social development. While clinical evidence of catch-up has been observed, less clear is the ability to correct for long-term malnutrition found in impoverished environments in the absence of extensive interventions. This paper investigates whether nutritional status at early age affects nutritional status at later ages among children using panel data from China, South Africa and Nicaragua. The key research question is whether children display 'catch-up' growth: do children who are malnourished at young ages have any chance of recuperating their health status as they grow older? And if they do, what are the key family and community level factors that enable catch-up growth to occur? The answer to this question is crucial for public policy due to the long term economic consequences of poor health. If catch-up growth is not possible, policy efforts must focus on early interventions that prevent malnutrition. If catch-up growth is possible, efforts can also be devoted to 'recovering' children who are already malnourished. Results show strong persistence in nutritional status across all countries, but not perfect correlation, indicating that some catch-up growth is possible. However household behaviors tend to worsen the possibility of catch-up growth.

Key words: catch-up growth, child health, malnutrition, developing countries
JEL Classification:

1. Introduction

The ability to correct childhood malnutrition, or for children to display 'catch-up growth', has wide spread population level implications for economic and social development. According to most recent estimates, over one third of all children under the age of five in developing countries suffer from some form of nutritional deficiency, with approximately 27% classified as underweight, 31% exhibiting stunting and 10% exhibiting wasting (UNICEF, 2006).[1] The causes of such malnutrition are complex and are generally thought to originate from underlying causes at the household level, such as inadequate food (insufficient quantity or nutritional quality), health (poor water/sanitation, quality of medical services), and care (maternal and child care practices or nurturing) (Smith & Haddad, 2000; Mosley & Chen, 1984). Even in their mild or moderate forms, nutritional deficiencies as indicated by anthropometrics have been linked to a range of adverse outcomes including reduced cognitive capacity and earning potential as adolescents and adults, increased risk of delivery complications for adult women, adolescent obesity and childhood mortality (See for example Glewwe, Jacoby & King, 2001; Popkin et al, 1996; Ong et al, 2000; Martorell, 1997). It is estimated that more than half of deaths among children under age 5 are due to underlying malnutrition (WHO, 2005). Research on the determinants of catch-up growth and under what conditions it may occur is thus applicable to economic development policy at a number of levels.

The term "catch-up growth" was first in introduced in the early 1960's to describe a phase of rapid linear growth under favorable circumstances which allowed a child to accelerate

[1] Classifications include moderate and severe forms of underweight (below minus two and minus three standard deviations from median weight for age of reference population), stunting (below minus two and three standard deviations from median height for age of reference population) and wasting (below minus two and three standard deviations from median height for age of reference population) according to WHO standard cutoffs. Data used was from the most recent available year by country, during the period 1996-2005.

toward his or her pre-illness growth curve (Prader et. al., 1963).[2] Since human growth follows a fairly regular curve throughout life course, theoretically a period of height velocity above the statistical limits of normality following a period of growth inhibition should be identifiable and sensitive to various interventions (Boersma & Wit, 1997). Although catch-up growth has been observed in laboratory and clinical settings, situations of wide-spread under nutrition in resource poor areas present a challenge for researchers. Past social science research has varied in its definition, measurement and statistical methodology in determining both (a) if full catch-up growth is possible; and (b) what factors may enable or contribute to correcting malnutrition. The objective of this study is to present a systematic discussion of the concept of catch-up growth, its application in social science research, and to provide more robust evidence of its existence by using independent population level panel data from three developing countries spanning different continents, races, cultures, and economic environments: China, South Africa and Nicaragua. The application of a common statistical approach to samples from such widely diverse populations allows us to comprehensively test the hypothesis of catch-up growth as a possible universal phenomenon among children in developing countries. Previous literature in the social sciences reports mixed results on this phenomenon because different studies not only use different sample designs (age ranges, populations, and lag lengths) but also different statistical methods (see review below for references).

Our statistical approach to this question is guided by a dynamic household economic model of human resource decision-making. In such a model, households apply current health inputs (food, care, medicine) to prior observed health status to achieve a desired health outcome in the subsequent period. Decisions about the amount of inputs to use depend on, among other

[2] The term "catch-down growth" has also been used to describe a decrease in the linear growth curve. Most research on interventions has been more concerned with improving nutrition standards rather than inhibitors of growth, and has therefore focused on catch-up growth.

things, the health endowment of the child. For example, a frail or sickly child may attract more attention and resources (inputs) from parents in an attempt to ensure his or her survival. Furthermore, the overall level and mix of inputs will depend on the parents' value or preferences for health. Thus, the OLS regression coefficient of previous nutritional status on current nutritional status, a common way to investigate the phenomenon of catch-up growth, will be biased because both current and previous nutritional status depend on the child's health endowment, which is unobserved by the researcher and by definition is correlated across time periods. Moreover, the extent of the divergence between the OLS coefficient of lagged health on current health and the 'true' coefficient provides insight on the type of behavior the household exhibits towards malnourished children. For example, a downward bias (OLS reports effects that are smaller than the 'true' effect) would be consistent with parents engaging in compensatory behavior; that is, providing additional inputs to malnourished children in order to boost their health status. On the other hand an upward bias in the OLS coefficient would suggest that unobserved behaviors related to preferences or health knowledge actually diminish the chances of catch-up growth.

Consequently, our empirical investigation of catch-up growth explicitly recognizes the potential endogeneity of prior health status, an approach that is not always taken in the literature (Adair, 1999; Vella et al., 1994). We identify lagged nutritional status using prior period price shocks as our identifying instruments. This is consistent with the dynamic optimization process of households because in such a process, long-term expectations of prices will affect health choices in each and every period, so it is only period specific deviations from these long term expectations that can be validly excluded from the health equation for other (subsequent) periods. Aside from a careful treatment of endogeneity, we assess the stability of our results to alternate sub-samples of the data, to see for example, whether catch-up growth is more likely for children who are previously malnourished, or whether it is more likely among younger children. We also investigate interactions among lagged nutritional status and household, family and community factors to see which specific factors inhibit or facilitate the process of catch-up growth.

2. Catch-up growth: a review

Research on catch-up growth although classically found in the medical and nutrition fields, has grown in popularity among economists and economic demographers. Neither field has a strong position regarding the possibility of full or partial catch-up growth nor under what conditions it may occur. For example Martorell et. al., 1992; Checkley et al, 1998; Monyeki, Cameron & Getz; Hoddinott & Kinsey, 2001, and Li et al, 2003, conclude that full catch-up growth is improbable, while Adair, 1999; Fedorov & Sahn, 2005; Saleemi et. al., 2001 conclude that full catch-up growth is probable. Although the underlying biological mechanism regulating catch-up growth is unknown, there is no evidence that short term malnutrition permanently damages growth plates, thus leaving the potential of catch-up growth physically possible (Boersma & Wit, 1997).[3] Much of the ambiguity in social science research is due to the variability in data such as age ranges, sample sizes, time between survey rounds, research design and model specification.[4] These factors have been shown to influence results and have the potential of introducing bias if proper methods to control for mediating factors and endogeniety are not implemented. Part of

[3] Much of the research involving biological mechanisms in catch-up growth have been conducted on animals or localized to single organs in the case of transplant studies. Two principal models have been postulated regarding biological mechanisms: (1) the neuroendocrine or Tanner's hypotheses and (2) the epiphyseal growth plate hypotheses. The first involves a central nervous system mechanism that compares actual body size with age-appropriate set point and then adjusts growth rate accordingly, while the second places the mechanism within the growth plate itself where previous growth-inhibiting conditions decrease proliferation of the stem cells within the plate, thus conserving proliferation potential. See Gafni and Baron for further discussion, 2000.

[4] Some of the various models have which have been used to study catch-up effect are the linear random effects growth model (Checkley et. al., 1998), correlation matrices (Cameron, Peerce and Cole, 2005), logistic regression (Adair, 1999), GMM (Fedrov & Sahn, 2001), and maternal fixed effects instrumental variables (MFE-IV) (Alderman, Hoddinott & Kindsey, 2003).

the objective of this paper is to provide results that are directly comparable by replicating the same model specification in three different populations, which may be subject to varying environmental conditions, genetic/racial endowments and socio-economic conditions affecting behavior, food choice and susceptibility to childhood malnutrition.

Clinically, catch-up growth has been defined as "a height velocity above the statistical limits of normality for age and/or maturity during a defined period of time, following a transient period of growth inhibition (Boersma & Wit, 1997)." However, it is acknowledged that the height velocity of a normal healthy individual fluctuates with seasonal or longer periodicity and therefore using a clinical definition of catch-up growth requires knowledge of a narrow and predictable growth tract as a benchmark.[5] More specifically, Boersma and Wit suggest that biologically three varieties of catch-up growth may be distinguished (Boersma & Wit, 1997). Type A is the classic case of catch-up growth, where when a 'restrictor' is removed, height velocity increases sometimes up to four times the mean velocity for age, until the deficit is eliminated and the growth curve returns to normal. This type of catch-up growth is common in infancy and childhood, and may be observed when a child recovers from starvation or illness. In Type B, the catch-up period is longer and growth velocity curve may not change, but simply extend into adolescence or puberty. Finally Type C is a mixture of types A and B, such that when the child experiences a favorable environment, there may be both a delay and prolongation of growth coupled with an increased height velocity. In settings where a controlled nutrition intervention is implemented and frequent anthropometric measurements are taken, these types of growth velocities may be distinguishable and are feasible indicators of catch-up growth. However, in field settings, outside clinical and laboratory research, the distinctions between

[5] In addition, this strict definition would require measurements of a previous period showing growth inhibition and must satisfy the condition of exceeding statistical normality in growth (Boersma & Wit, 1997).

these three types are often blurred. In social science research examining population level child growth, nutrition related measurements may be years apart and the variety of catch-up growth may only be hypothesized based on the age ranges of sample children. Examining pre-adolescent samples, such as the three panels presented here, is the simplest case, since growth differences in puberty need not be accounted for. Therefore, in these samples, nutrition improvements should suggest a lower bound of catch-up growth potential, only capturing Type A and/or Type C categories of catch-up growth.

Outside of clinical research, in the absence of reliable height velocity measurements, social scientists have sought alternate measures of improvement in childhood nutrition. Although there is large body of research investigating improvement of nutritional status, there is no standard definition of "catch-up growth." In fact, in contrast to clinical research, often no distinction is made by social scientists between compensatory growth, catch-up growth and correcting deficiencies in nutritional status. Ultimately, economists and public health researchers are most concerned with the potential of permanent damage caused by childhood malnutrition. The relevant question essentially becomes: if a child exhibits moderate forms of malnutrition, are they 'locked into' a lower growth trajectory with a lower growth potential? If the answer is no, then relevant policy influential factors which may promote catch up are also sought.[6] Researchers have sought to evidence this question using a variety of definitions. For example, Adair defines catch-up growth as a recovery from stunting over an 8.5 or 10 year panel from the

[6] Biologically, six factors have been hypothesized to affect the extent of compensatory growth: (1) the cause of undernutrition (for example severe protein restrictions may have more harmful effects than severe energy restriction; (2) the severity of malnutrition; (3) the duration of malnutrition (4) the stage of development of the child at the start of malnutrition (where children of younger age are more affected); (5) the relative rate of maturation; (6) the pattern of realignment with pre-illness growth curve (the higher the plane of nutrition upon realignment, the more rapid and greater the recovery) (Wilson & Osbourn, 1960).

Philippines (Adair, 1999)[7]. In 2000, Ong et al defined "clinically significant catch-up growth" as an increase in 0.67 z-scores in weight from birth to two years of age based on growth behavior in a sample of South African children (Ong et al, 2000). Others consider any type of positive gain or improvement as a catch-up in nutritional status (Knops et. al., 2005). Using an economic framework, Federov and Sahn define catch-up growth as a relationship between height in the previous period and height in the current period using a panel of Russian children. The authors hypothesize that if no significant association is found, the conclusion can be made that damage incurred in the past does not transmit to the future period (Fedorov & Sahn, 2003). Note that Fedorov and Sahn is one of the few studies that recognizes the endogeneity of passed height while specifically examining current height, which they also control for using an instrumental variable approach, although their implementation is slightly different from the one in this paper.

In addition to contrasting definitions and model specifications applied to explain the catch-up growth phenomena, it has been further argued that the choice of actual nutrition indicator has implications on conclusions. This analysis uses height for age z-score as an indicator of catch-up growth following the rationale presented recently by Cameron, Preece and Cole (2005). The authors give three main reasons why z-scores are superior to other previously used measurements. The first has to do with measurement of height (or other single variable such as weight or height increments), where they note the correlation between baseline and follow-up height are dependent on the ratio of height standard deviations of the two measurements, which itself varies with age.[8] In contrast z-scores are not subject to this bias because they already take into consideration reference groups of equal age. The second

[7] Adair (1999) also examines height increments between two intervals, where children are grouped according to their studentized residuals from a regression of height at time t on height in time t-1. Catch-up growth is defined as a residual of >1.

[8] For example, the expected change in height can be modeled by the equation which relies on measurements of the standard deviations: $\Delta h = E(h2) - h1 = rh1\ (s2/s1) + c - h1 = h1(r(s2/s1)-1) + c$ where h1 is baseline height, h2 is follow-up height, r is the correlation between the two, s1, s2 are standard deviations of each sample and c is a constant. See Cameron, Preece and Cole, 2005 for discussion of differences in measurement.

justification is that demonstration of catch-up growth needs to be compared with growth in a control group, which z-score measurement fulfills but a single height measurement does not. Third and most importantly, the authors note that by using z-score measurements, catch-up growth may be separated from correlations predicted by regression to the mean in a large sample.[9]

3. Theoretical Framework and Empirical Model

A. Theoretical framework

In economic models, child health and nutrition can be thought of as either a household production process or a human capital accumulation process (Strauss & Thomas, 1995; Federov & Sahn, 2003). Nutrition is assumed to contain components of both 'stock' and 'flow' variables. For example, some components of nutritional status are long term cumulations or 'stocks' of inputs such as height or resistance to disease. Other components of child nutrition are 'flow' variables, such as caloric intake, which are produced with current inputs and consumed in the current period. This is not the case for stock variables, which may be carried over for consumption in a future period. These types of variables can be modeled using a dynamic health production function, which represents the technology available to a household seeking to use inputs to produce better health (see for example Cebu Study Team, 1992):

$$(1)\ H_t = f(\boldsymbol{N}_t, \boldsymbol{N}_{t-1}, \ldots, \boldsymbol{N}_1, \boldsymbol{N}_0, \boldsymbol{X}_t, \boldsymbol{X}_{t-1}, \ldots, \boldsymbol{X}_1, \boldsymbol{X}_0, \mu_i \,|\boldsymbol{G});$$

where H_t represents current health and $\boldsymbol{N}_t$ represents a vector of endogenous nutritional inputs at time t. Vector $\boldsymbol{X}_t$ represent exogenous characteristics at the individual, household and community level which affect health in time t. Inputs as far back as from birth ($t=0$) may affect

[9] The argument is that if a measurement is compared with a second correlated measurement in the same sample, the second measurement is on average closer to the population mean than the first. Thus, stunted children will "regress to the mean" and become relatively less stunted over time, and that regression to the mean will be most obvious in children with the worst baseline status (Cameron, Preece & Cole, 2005).

the current stock of health and are conditional on $\boldsymbol{G}$ or genetic endowment[10] The μ_i term captures unobserved (to the researcher) variables of the child such as frailty or susceptibility to disease. The right hand side of equation (1) may be reduced by making the assumption that one measurement of lagged nutritional status is sufficient to measure the stock or accumulation of all previous inputs (Strauss & Thomas, 1995). This assumption has been adopted by subsequent theoretical and empirical evaluations (Fedorov & Sahn, 2003; Cebu Study Team, 1992; Hoddinott & Kinsey, 2001). Thus, current health may be reduced to a function of lagged health, current period nutritional inputs and current period individual, household and community exogenous variables related to health, conditional on genetic endowment:

$$(2)\quad H_t = f(\boldsymbol{H}_{t-1}, \boldsymbol{N}_t, \boldsymbol{X}_t, \mu_i \,|\, \boldsymbol{G});$$

Each household is assumed to use a utility maximizing framework to determine the optimal level of input for each child's health production. Utility is maximized inter-temporally subject to budget and time constraints:

$$(3)\ \max_{\{Ct,\, Lt,\, Mt\}} U\,[u_1(\boldsymbol{C}_1, \boldsymbol{L}_1, \boldsymbol{H}_1), u_2(\boldsymbol{C}_2, \boldsymbol{L}_2, \boldsymbol{H}_2), \ldots, u_T(\boldsymbol{C}_T, \boldsymbol{L}_T, \boldsymbol{H}_T)],\ t = 1,\ldots,T;$$

where utility of the current period depends on consumption of goods $\boldsymbol{C}$, leisure $\boldsymbol{L}$, and the health stock of children $\boldsymbol{H}_i$ in $t = 1,\ldots,T$. It is assumed that $\boldsymbol{U}$ is intertemporally separable and each u is increasing and quasi concave.[11] In each period t, the household faces the budget constraint:

$$(4)\ p_t^C \boldsymbol{C}_t + p_t^N \boldsymbol{N}_t = w_t(\boldsymbol{E}_t - \boldsymbol{L}_t) + \boldsymbol{Y}_t + \boldsymbol{A}_{t-1}(1+r_t) - \boldsymbol{A}_t,\ \ t = 1,\ldots,T;$$

where p_t^C and p_t^N are prices in period t of consumption goods and nutritional inputs, w_t is the wage rate, $\boldsymbol{E}_t$ is the time endowment, $\boldsymbol{Y}_t$ is unearned income, $\boldsymbol{A}_t$ and $\boldsymbol{A}_{t-1}$ are assets and r_t is the

[10] There has been evidence that even before birth, children's 'stock' of health may be influenced by nutritional inputs of the mother during pregnancy (in utero). See Li et al (2003) for discussion of evidence. In this case, $t=0$ would indicate time at conception rather than birth. However, for model simplification, it is assumed that stock starts accumulating at birth.

[11] These assumptions are in line with previous work regarding child health production functions (Hoddinott & Kindsey, 2001; Foster, 1995, Fedorov & Sahn, 2003). In addition it is assumed that fertility decisions are taken as given and that there exists a household utility function.

real interest rate. All other variables are as previously defined. Equation (3) is maximized subject to equations (2) and (4) to obtain the optimal input N^* in each time period:

$$(5)\ N_t^* = f(\boldsymbol{H}_{t-1}, p_t^C, p_t^N, w_t, \boldsymbol{E}_t, \boldsymbol{Y}_t, \boldsymbol{A}_t, \boldsymbol{A}_{t-1}, r_t);$$

Finally, the dynamic conditional health demand function for child *i* can be derived by placing equation (5) into equation (2):

$$(6)\ H_t = f(\boldsymbol{H}_{t-1}, f(\boldsymbol{H}_{t-1}, p_t^C, p_t^N, w_t, \boldsymbol{E}_t, \boldsymbol{Y}_t, \boldsymbol{A}_t, \boldsymbol{A}_{t-1}, r_t), \boldsymbol{X}_t, \mu_i | \boldsymbol{G});$$

Equation (6) displays current stock of health (or nutrition) as a function of its value in the previous period, contemporaneous prices of consumption and health inputs, wage, time endowment, unearned income, assets, the interest rate, exogenous characteristics and genetic endowment; this is the equation that guides our empirical implementation below.

B. Empirical model

The theoretical model above is assumed to be non-stochastic, but empirically the μ_i term may pick up unobservable errors correlated with the child or household. These errors are unknown to the observer and may or may not be known to the household. For example, as previously noted, the error term may include components such as frailty of the child or parenting methods which affect the level of care the child receives. Consider the empirical counterparts to (6) for two time periods that we can estimate given the data at hand:

$$(7)\qquad HAZ_{it-1} = \beta_0 + \beta_1(\boldsymbol{X}_{i\,t-1}) + \beta_2(\boldsymbol{X}_{h\,t-1}) + \beta_3(\boldsymbol{X}_{c\,t-1}) + \varepsilon_{t-1} + \mu_i$$

$$(8)\qquad HAZ_{it} = \beta_0 + \beta_1(H\hat{A}Z_{it-1}) + \beta_2(\boldsymbol{X}_{i\,t}) + \beta_3(\boldsymbol{X}_{h\,t}) + \beta_4(\boldsymbol{X}_{c\,t}) + \varepsilon_t + \mu_i$$

In equations (7) and (8), $\boldsymbol{X}_i$ represents a vector of time specific child level characteristics which are associated with child nutrition; similarly, $\boldsymbol{X}_h$ and $\boldsymbol{X}_c$ represent time specific household level and community level variables associated with child nutrition and ε_t and ε_{t-1} are period specific shocks that are not correlated across periods. The key empirical issue is that μ_i (the child specific health endowment or fixed family health practices) appears in each period as a determinant of health status, and is thus correlated with lagged height in (8).

We use instrumental variables to purge (8) of the correlation between lagged height and μ_i. Following Alderman et al (2001) and Handa & Peterman (2006) we use prior period price shocks to identify lagged height in the system, where price shocks are defined as the deviation of current prices from their expected long run trend. We control for differences in expected long run prices with regional dummy variables, and include contemporaneous prices as an indicator of the actual realization of the expected price in each period; the difference between the (contemporaneous) realized price and the long-run expectation is an indicator of the innovation in prices, or the price shock. Thus our empirical implementation includes in (7) and (8) regional indicators to capture long run price trends or expectations, and current prices to capture the innovation in prices. A strategy that includes only contemporaneous prices in each of (7) and (8) would not control for long-term expected prices in the household decision rule; to the extent that this information is picked up by contemporaneous prices in (7), these prices would not be orthogonal to the error term in (8) and would thus not be valid identifying variables.[12]

If the coefficient on past height for age z-score is significant and large in magnitude, then catch-up potential may be limited. However, if lagged height for age is not significant or is small in magnitude, other factors have significant and perhaps dominating associations with current height for age. A coefficient of 0 would imply no association between past and current height for age, or that complete catch-up growth is possible. A coefficient of 1 would imply a one to one relationship between current and past nutritional status, or complete persistence in health status.

4. Data and variables

[12] See Alderman, Behrman, Lavy & Menon (2001) and Handa & Peterman (2006) for a full discussion of this issue and sensitivity tests among different specifications of the instruments set in these types of models.

A. Data

The data used come from three independent population level panels surveyed during the years of 1989 to 2001. The CHNS is a panel of approximately 4,400 households in nine Chinese provinces, designed and implemented by the Carolina Population Center at the University of North Carolina at Chapel Hill.[13] The objective of the survey is to provide information on the social and economic transitions and their potential affects on nutrition and health indicators. Individuals and households were surveyed over six waves in 1989, 1991, 1993, 1997, 2000 and 2004. Information was collected on health, nutrition, employment, household possessions, and education on the household level, as well as matching community level information on markets, health facilities and other social services. A multistage, random cluster process was used to sample the population from each of the province. Counties in each province were stratified by three levels of income and a weighted sampling scheme was used to randomly select four counties in each province (Carolina Population Center, 2005). In addition to the selected counties, the provincial capital and a lower income city were selected to be part of the sample. Villages and townships were randomly selected within the sample counties as well as urban and suburban neighborhoods within cities. For the panel between 1989 and 1993, 190 primary sampling units were selected, consisting of 32 urban neighborhoods, 30 suburban neighborhoods, 32 towns, and 96 villages.[14] Health and nutritional data were collected for children under the age of 7, generating a final panel of approximately 1,224 children.

The South African data are part of a panel of approximately 1390 households in the KwaZulu-Natal province of South Africa conducted in 1993 and 1998[15]. At the time of the

[13] Provinces include Guangzi, Guizhou, Heilongjiang, Henan, Hubei, Hunan, Jiangsu, Jiaoning and Shandong.
[14] Quality control measures uncovered problematic procedures in several provinces during the 1989 panel. These have been subsequently corrected and reliable measures for the 1989 panel are now in use (Carolina Population Center, 2005).
[15] The baseline survey was part of the Project for Statistics on Living Standards and Development (PSLSD) implemented by a consortium of South Africa survey groups headed by the South African Labour and Development Research Unit (SALDRU).

baseline survey, KwaZulu-Natal contained nearly 1/5 of the countries 40.6 million people, making it South Africa's largest province (Carter et. al, 2003). The survey was commissioned by the South African Government as part of the effort to understand the dynamics of poverty and inequity of apartheid and the changes which took place after the abolishment of apartheid in 1994. During the mid 1980's and early 1990's the province suffered considerable political violence and unrest and consequently did not hold its first democratic local elections until 1996, one year after the rest of South Africa. KIDS is a collaborative project of the International Food Policy Research Institute, the University of Natal-Durban, the University of Wisconsin and the Southern African Labour and Development Research Unit at University of Cape Town. It covered a wide range of topics including demography, household services, household expenditure, educational status, land access and use, employment and income, health status and anthropometry. The baseline sample was selected using a two-stage self-weighting design. In the first stage, clusters or villages were chosen proportional to population and percentage of the population ethnically African from census enumerator sub-districts. Villages were then ranked and selected at a fixed interval starting at a randomly selected point. In the second stage, all households in each chosen cluster were randomly selected on an interval which allowed on average 25 households or 125 individuals per village. Although the baseline portion of the sample contains households of all races, based on the number of white and colored households surveyed in the 1993 cross section, it was decided not to re-survey these ethnic groups in the 1998 round. This decision was taken because the small absolute number of white and colored households and the geographic concentration of these households would have yielded unreliable

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Subsequently, the follow up in 1998 was designed to match the baseline with modifications (May et. al, 2000). A second follow-up, the 2004 survey was recently released in July 2006 by the University of KwaZulu Natal, School of Development Studies.

results in ethnic analyses (Carter et. al., 2003). The final sample of matched children with valid anthropometric measurements is 530 and ranges from age 0 to 5 years at baseline.

The final panel is taken from the 1998 and 2001 EMNV designed by the National Institute for Statistics and Census (Instituto Nacional de Estadisticas y Censos) with technical assistance from the World Bank. The purpose of the survey was to provide data on household living conditions, and community level infrastructure to inform Governmental poverty alleviation projects. The sample was geographically stratified and chosen in a serpentine method within census segments, pre-stratified to ensure a comparison of urban/rural as well as to include households in each of geographic department WB, 2002).[16] The final sample of matched children with valid anthropometric measurements and household variables in both years is 492 and ranges from age 0 to 2 years at baseline.[17]

B. Variables

We try and mimic the exact same specification for each system of equations across our three panels. As indicated in equations (7) and (8), control variables are grouped into individual, household and community level variables believed to be associated with child health. Individual level variables include age of children (age dummies of 0-6 months, 7-12 months, 13-24 months, 25 to 60 months and over 60 months are used in the first stage regressions, while age in years is used in the second stage regressions), indicator of sex (male), ethnic dummies[18], mother's height to control for genetic endowment and/or parental human capital, mother's age and indicator of

[16] The serpentine sorting method sorts in alternating ascending and descending order, so that any two consecutive records in the sorted file are more similar with respect to their vales of the sorting variable than in traditional sorting. Nicaragua has 15 departments and two autonomous regions; each department is further divided into municipals, which are further divided into census sectors and census segments (See WB, 2002 for further discussion of baseline sampling framework).

[17] EMNV was the only data set without consistent person level id codes across both years. To create a panel, children were matched by household, sex and exact birth date (month, day and year). In addition, children who matched on household and sex were examined if their month and year matched, or if all other variables matched except birth year was off by exactly one year. In this case, the correct birth year was recovered by examining feasible height/weight measurements in relation to matched children and z-scores were recalculated using the new matched z-score information.

[18] These include a dummy variable for East Indian in the KIDS and for Indigenous Indian in the EMNV.

low mother's education. The age splines represent a breakdown of groups which may be at different risks for disease susceptibility and nutrition faltering. It is usually agreed that age between 6 and 24 months are the most critical because of introduction to alternate feeding. Mother's age and education signal knowledge in child rearing and are proxy indicators of earning potential, access to information and higher woman's status. Household level variables include household size, travel time to nearest health clinic and a wealth score created by principal component analysis.[19] Community level variables include average wage, regional dummy indicators and a price basket of staple food items for each country. Descriptive statistics for all control variables at baseline are presented in Table 2.

Complete case analysis was used for all three data. The exception was information on the mother of the child and information on community level variables. Mother's information is expected to be missing if the mother is deceased, not living with the child, or in some cases if the mother was not present at the time of the interview (to collect anthropometry measurements). The missing values on mother's education were replaced with the highest female education in the household. Mother's age is replaced by the sample mean, mother's height is imputed and a binary indicator is included as a control variable for observations which are missing mother's information. Missing community level prices were replaced step wise with the average of the district or municipality in which the community was located.[20]

C. Sample attrition

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[19] The variables used in the wealth score differ slightly between data sets based on availability and variation in identifying economic status in each country. In each case, either per capita expenditure (KIDS) or per capita income (EMNV and CHNS) were included, as well as assets dummy indicators and water/sanitation variables. See Table 5A in the Appendix for list of variables used for each country. The same variables were used for both years and the validity of the index was tested against single indicators of socio-economic status.

[20] For the CHNS, state stores and free market stores were surveyed in each community for a basket of staple goods. The KIDS surveyed a basket of 41 food and 9 non-food basic commodities in both informal and formal sectors for each "cluster". An average of these two prices was used as the reported price. In the case of EMNV, the price questionnaire was administered at the community level in rural areas and at the municipal level in urban areas. The goods included in the questionnaire were based on the consumer basket for the urban sector and included 32 food items and 18 non-food items. Three price quotations were collected for each community/municipal.

Non-random panel attrition is a concern when working with longitudinal data, especially when the years between survey rounds increases. In theory, the number of households dropped from any given panel depends on the mobility of the target population, the political situation in the country, survey policy on tracking households and the time elapsed between survey years and the rate at which households refuse interviews. In practice, there is also the possibility of errors in the fieldwork, inability to locate houses and finding members to interview. The total number of successful re-interviews by household was 90.7% (CHNS), 84.1% (KIDS) and 75 % (EMNV) (Carolina Population Center, 2005; May et. al, 2000; Stampini & Davis, 2003).[21] For this analysis, the concern is child attrition due to poor health, or in extreme cases, death which potentially may bias results. To verify that unhealthy children where not dropped from the panel or in a systematic way as compared to healthy children, t-tests were conducted on sample means within the final panel and those children who had dropped, in the baseline. Results show that there was no significant non-random panel attrition within the KIDS and EMNV data.[22 23] Within the CHNS the children who were not re-interviewed were statistically significantly different than those contained in our panel. However, the mean height for age of these dropped children was 0.18 z-scores *higher* than those who remained in the panel, thus the hypothesis that unhealthy children were more likely to be included in the attrition group is not supported.

5. Results

A. Descriptive statistics

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[21] Stampini and Davis (2003) test the exogeniety of attrition in the EMNV and conclude that attrition is not a major problem using BGLW, Heckman and FGM tests. See Stampini and Davis for further discussion and results.

[22] The t-test p-values for where H_0=mean values of the z-score at baseline for both groups are equal are as follows: EMNV p = 0.31, KIDS p= 0.13, CHNS p=0.01. Overall attrition rates for CHNS were calculated from initial figures of 3,795 households sampled in 1989 which were reduced to 3,441 households in 1993, including new households formed from sample households who resided in sample areas.

[23] Selected children were purposefully dropped from each panel, limiting height for age to biologically feasible values. Typically values outside the range of normality are the result of errors in data entry or measurement rather than true extreme growth. Here the fixed exclusion range is used, where scores of <-5 and >+3 are dropped (WHO, 1995). This resulted in the following reductions: 7 (CHNS), 11 (EMNV).

According to UN country level statistics averaging data from 1995 to 2004, the percentage of children less than five years old displaying under nutrition (height for age) in each country is approximately 16% (China), 25% (South Africa) and 20% (Nicaragua) (UNDP, 2004). Table 1 presents means of height for age z-scores and years of survey in each panel. The baseline and follow up values of height for age in China are the worst (-1.23 and -1.16), closely followed by South Africa (-1.01 and -.97). Nicaraguan children start significantly better off (-0.37), however fall behind in the follow up (-1.01), presumably due to the adverse health effects of Hurricane Mitch which hit the country in late 1998. These distributions follow a fairly normal curve and are presented as kernel density graphs in Figures 1-3. In addition, a descriptive analysis of the percentage of movement within each sample is presented in Table 1, where the cut point is a z-score of -1.0. In each case, the percentage of children remaining either below or above -1.0 over the panel periods is greater than those moving from above to below 1.0 z-scores and vise versa. For example, among the CHNS data, approximately 45% are less than -1.0 z-scores in both years and approximately 32% are above -1.0 z-scores in both years. Smaller percentages improve or regress over the panel period (13% and 11% respectively). In comparison to China, South Africa has a greater percentage of improvements and regressions in nutritional status, while Nicaragua shows more regressions and fewer improvements. In all cases there is enough movement to confidently examine changes in nutritional status.

Table 2 presents the remaining core control variables measured at baseline unless otherwise indicated. Children and their mothers in EMNV are on average younger than in CHNS and KIDS. Mother's in all three samples on average are of similar stature, with the Nicaraguan mothers slightly shorter (153.2 cm) in comparison to Chinese mothers (155.5 cm) and South African mothers (157.5 cm). Height may in part be distinctive among ethnic groupings, however these account for a relatively small percentage of the sample. Approximaly 11% of the South African sample is East Indian and 3% of the Nicaraguan sample is identified as Indigenous Indian. As would be expected, family size of Chinese households is the smallest (4.95 members), followed by Nicaraguan families (7.23 members) and South African families (8.71 members). The low category of mother's education contains 12% (CHNS), 46% (KIDS) and 19% (EMNV) of the sample respectively. The percentage of households residing in urban areas varies from 9% in South Africa to 45% in Nicaragua

B. Stage one regressions for lagged height

The viability of the instrumental variables approach we adopt depends critically on the strength of the instruments in predicting the endogenous variable. If equation (7) poorly predicts (HAZ_{it}), then replacing the actual value with the predicted value only replaces the value with a noisy, poor measure. The R^2 of the first stage (7) is a good approximation of the strength of the instruments, where an R^2 under 0.10 is a poor predictor (Bollen, Guilkey & Mroz, 1995). In addition, joint F-test's on the instruments in the first stage give further validity to the use of the instrument set. Regional indicators and contemporaneous community level prices are used to identify the identify HAZ_{it} in the first stage. The baskets of prices vary for each data set, but include staple foods of each country which are expected to be associated with nutritional status. For example, prices used to identify lagged nutrition in the KIDS data are community level prices of formula, fresh milk, rice, eggs, maize, potatoes and soap. Results of the first stage estimates are presented in Table A1 in the Appendix, and the instrument list, R^2 values and corresponding F-statistics are included at the bottom of the table. All R^2 values are over 0.10 and all prices baskets pass the rule of thumb test with a joint significance of 1%.

C. Impact of lagged height on current height

Table 3 presents a summary of the key results from the second stage. For each data set the OLS coefficient of lagged height predicting current height is displayed, as well as the "preferred" instrumental variable coefficient which accounts for the endogeneity of lagged height. In all cases in the full sample the OLS coefficient of lagged height is positive and significant, as is the instrumented coefficient. Note that the bootstrapped standard errors of the preferred estimations are often double and even 3 times the size of the OLS standard error. [24] Note also that the IV point estimate is consistently lower than OLS, though still statistically significant. In the case of China, the point estimate decreases by 40%, in South Africa by 14% and in Nicaragua by 44%. This decrease indicates that once we control for unobserved heterogeneity influencing health behavior, the possibility of catch-up growth improves. In other words, parents do not seem to display compensating behavior. Instead, unobserved preferences or knowledge negatively affect current and previous health. Alternatively, parents engage in investment type behavior and favor innately stronger children. Both of these scenarios reduce the possibility of catch-up growth.

Table 3 also presents results for the sub-sample of children who were at least mildly malnourished in the base year (z-score of less than -1). This group is of interest for two reasons. First, they are at higher risk and therefore of policy interest. Second, there is more room for improvement among this group, suggesting that the estimated coefficient on lagged height would be smaller among this group--this is the familiar regression-to-the-mean story. In two of the three country cases the OLS impact of lagged height is smaller in this sample, and the IV coefficients, which account for behavior, are slightly smaller and no longer significant. The lack of significance is partially attributable to smaller sample sizes in these two surveys; larger sample sizes would probably deliver statistically significant point estimates as they do in the case of China.

[24] The bootstrapped standard errors are based on 1000 replications with replacement.

Full results for the OLS and IV regressions are reported in Tables 2A-4A in the Appendix. In China mother's height, household wealth and mean village wages make significant positive contributions to current height for age. Mother's low education is negatively associated with current nutritional status, although not significant. In South Africa, mother's height and indicator of East Indian make positive contributions, while age is negatively associated with current nutritional status, while mother's low education is also insignificant. In Nicaragua, mother's height, household wealth and child's age are significant and contribute positively, while the indicator of Indigenous Indian and indicator of male contribute negatively. Again, mother's illiteracy is negatively associated with current nutritional status but is insignificant. In each of the second stage regressions, geographic indicators of province or region are significant.

As an additional sensitivity analysis, we replicate our primary model but limit the sample to children less than 2 years of age at baseline.[25] This is done to test the hypothesis that timing of nutritional insults matter, and that children who are younger when the insult occurs are more severely affected in the long term than older children (See for example the discussion in Hoddinott & Kinsey, 2001 and Glewwe & King, 2001). Our results show no marked difference from the main effects reported for the full samples and so are not presented (but are available from the authors upon request). This implies that the effect of lagged health is very similar across all children under approximately six years of age, similar to conclusions found by Vella et. al. (1994) using a panel of children from Northern Uganda.

We also replicate our primary model using height in centimeters instead of the height for age z-scores, and the impact of lagged height on current height using this approach is reported in the bottom panel of Table 3. These results show that using height as an indicator increases the

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[25] This resulted in changes of sample sizes for CHNS (N = 327) and KIDS (N= 157). There was no change for EMNV (N = 472), as the full sample was already limited to this age.

point estimates in the OLS models by 40% in China, 60% in South Africa and 54% in Nicaragua. However, the preferred models which control for endogeneity are significantly smaller, decreasing by 70% and 5% in the cases of China and Nicaragua, while the South African estimates stay essentially unchanged (relative to the IV estimates using the z-score in the same country). The preferred estimates are consistent with Cameron, Preece and Cole, who claim that catch-up should be more evident based on height measurements compared to z-scores. They use a three year panel of 495 stunted South African children age two at baseline in the Birth to Ten Cohort, but their statistical methods do not control for endogeneity (Cameron, Preece & Cole, 2005). Fedorov and Sahn do control for endogeneity in their Russian sample but use actual height (instead of the z-score) as their indicator of catch-up growth. They report an OLS estimate of 0.35 for lagged height on current height, which declines to 0.22 once they control for the endogeneity of lagged height. Their results thus also support the notion of investment behavior on the part of parents or household decision-makers. Based on the discussion in Cameron et al. and our own sensitivity analysis in Table 3, the Fedorov & Sahn estimates are likely to be upper bounds of the catch-up growth effect based on z-scores

D. Extensions

In this section we explore the possibility that catch-up growth varies with family background and environmental factors. The existence of facilitators (or inhibitors) of improved growth are of policy interest because these factors could be used for targeting interventions to malnourished children or be the objective of interventions themselves. We explore interactions between lagged height and mother's schooling, mother's height, distance to nearest health facility, household wealth, and the sex of the child. Mother's height and schooling have themselves been the focus of studies on the determinants of childhood malnutrition and so we first provide a brief discussion of their potential role in the production of infant health.

One possible role of maternal height is as an indicator of genetic potential. Although there is some evidence that the genetic component of the differences in children's height is on average small in comparison to environmental influences, parental height is still a significant component of potential height (Golden, 2005). In developing countries though, the idea of height potential is somewhat of a problem if the parents themselves are short because of malnutrition when they were children. This implies two very different definitions of catch-up. One is a catch-up to a standard height based on a healthy population in which there is no circular trend, and the other is a catch-up to what is expected of the child, given trends of malnutrition. To catch-up by international standards or essentially correcting for generations of malnutrition may be expecting more then is plausible from any given child. However, there is evidence that suggests that not only does mother's height indicate inherited stature, but also in part inherited disease susceptibility due to its significance on survival rates, even after controlling for other characteristics (Thomas, Strauss & Henriques, 1990). In this way, mother's height could be thought of as a control for the "human capital" of the mother or parents (Strauss & Thomas, 1995). Further, it has been suggested by examining interaction terms between parental height and age of the child that significance of parental height increases as the child ages (Cebu Study Team, 1992). This finding may explain the insignificance of mother's height in our first stage regressions when the child is of a younger age.

Mother's education has been cited in numerous studies as showing strong associations with nutrition status of children (Barrera, 1990; Strauss & Thomas, 1995; Thomas, Strauss & Henriques, 1990). Education may signal knowledge in child caring, as well as a proxy indicator of earning potential, access to information and higher woman's status. In all three data sets, mother's education is not a significant determinant of child health, suggesting that it might be correlated with other control variables in the equation such as mother's height and wealth score. [26] For example, Barrera found that estimates for mother's education fell by between 20 and 50 percent when mother's height is controlled for using data predicting height for age in the Philippines (Barrera, 1990). Similarly, using data from Brazil predicting child survival, Thomas, Strauss and Henriques find that the coefficient on mother's education drops between ¼ and ⅓ in size when household income is introduced (Thomas, Strauss and Henriques, 1990).

We experimented with separate specifications that exclude mother's height and household wealth and find that the coefficient of mother's education is not sensitive to the exclusion of height, but is sensitive to the exclusion of wealth in Nicaragua and China. Specifically, the impact of maternal education in the stage one regressions increase (in absolute terms) when wealth is excluded from the model in these two countries, while in the second stage, the impact also increases in absolute value and becomes statistically significant in the Nicaragua sample.

Table 4 reports the coefficient estimate of the interaction term between lagged height and the indicated variable, both for the full sample of the malnourished sample for each country. Lagged height is treated as endogenous as is the interaction term, and reported t-statistics are based on bootstrapped standard errors. The interpretation of the sign of the interaction term depends on the way the variable is measured. If higher values of the variable are thought to be positively correlated with height, then a *positive* interaction indicates *complements* while a negative one indicates the two factors are substitutes. However if the variable is measured such

[26] There has been evidence that maternal education may actually have a negative affect on breastfeeding and subsequent child health, however this does not dominate the alternate beneficial affects. The reasoning given behind this outcome is the increased opportunity cost of mother's time for higher educated mothers (The Cebu Study Team, 1991).

that lower values are thought to be positively associated with better nutrition (such as distance to health facility, and mother's education since our indicator is for low maternal education) than the opposite is the case: a *negative* coefficient indicates *complements* and a positive one substitutes. Since the catch-up growth hypothesis is supported when the impact of lagged height is closer to 0, factors that are substitutes with lagged height improve the chance of catch-up growth.

The full-sample results from Table 4 do not show any consistent patterns in terms of substitutes for lagged height, highlighting the usefulness of examining these relationships across different populations and sample designs. Maternal education is a substitute for poor health in South Africa, indicating that children with better educated mothers are more likely to improve their z-score than other children. On the other hand, in China household wealth is an important complement to child growth, and maternal height is a significant complement in Nicaragua. There are no significant interactions among sex or distance to health facility and lagged height.

There number of significant interactions reported in Table 4 is larger for the sample of malnourished children but again, no consistent generalization can be made across populations. Household wealth continues to be a complement in China, but is a strong substitute in Nicaragua and South Africa; in these latter two countries then, wealthier households are better able to facilitate catch-up growth among children relative to other households. Indeed in China there is a clear pattern of rising inequality in health status among the sample of malnourished children, with household wealth and maternal height all serving as significant complements, and thus inhibitors to catch-up growth. In Nicaragua on the other hand, both household wealth and maternal height are substitutes, and thus enablers of catch-up growth.

6. Conclusions

The possible existence of catch-up growth has attracted the attention of economists and public health researchers due to the growing evidence that early childhood malnutrition is associated with a range of adverse outcomes at later life stages. Researchers have approached the question in different ways, using a variety of sample designs (lag lengths and age groups), statistical techniques and measures of nutritional status. Three key points stand-out from our review of the literature: 1) the endogeneity of lagged health on current or future health is not fully accounted for in many of the studies; 2) the preferred measure of nutritional status is in z-scores and not actual height in centimeters or ranges as is common in much of the literature; 3) there is no consensus on the possibility of catch-up growth based on population samples, but this is not surprising given the variation in statistical techniques, measures and sample design.

We attempt to make headway in the debate on catch-up growth by presenting results from three widely varying population based samples using identical statistical techniques, controlling for endogeneity of lagged health, and measuring height in z-scores. Our estimates of the association between lagged height and current height range from 0.28 to 0.42 for these three very different populations, indicating that while previous health does not track future health perfectly, there is still significant persistence in health status for young children. These estimates do not account for household health-related behavior. When such behavior is accounted for, our point estimates are reduced to the 0.22-0.25 range. While this drop implies a greater possibility of catch-up growth, the point estimates are still significantly different from 0, indicating some persistence in health status. Our basic result is robust to choice of sample. When we apply our statistical methodology to height measured in centimeters we find more support for catch-up growth, but this is to be expected because of ‘regression-to-the-mean’ effects that occur with this measure.

The magnitude of the OLS and IV point estimates indicates that OLS is biased upward. Thus, household behavioral decisions about children's health reduce the possibility of catch-up growth. This is consistent with several alternative explanations of household behavior: 1) that households pursue an investment or wealth maximizing strategy and invest more in children with better innate health endowment, or; 2) that (positive) household knowledge and caring practices are positively associated with health endowments and thus exacerbate initial differences in health.

Our investigation of factors that could facilitate catch-up growth revealed no clear pattern across regions, but some suggestive conclusions within regions. For example, in the initially malnourished sample, household wealth facilitates catch-up growth in Nicaragua and South Africa but not in China, while in the full sample, maternal height (Nicaragua) and education (South Africa) also facilitate catch-up growth. In China, maternal education enables, while maternal height and household wealth inhibit catch-up growth, implying an increasing pattern of inequality in health status over time.

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Table 1: Height-for Age z-score Comparisons

	CHNS China	KIDS South Africa	EMNV Nicaragua
Panel survey years	1989-1993	1993-1998	1998-2001
Ages of Anthro measurements (months)	0-96	0-80	0-60
Full sample sizes	1,224	530	492
Mean z-score in base year	-1.23	-1.01	-0.37
Mean z-score in follow up year	-1.16	-0.97	-1.01
Percentage in panel (where cutoff is -1):			
Catching up:*	12.66	19.25	6.91
Regressing:**	10.62	17.74	23.78
Remaining undernourished:	44.93	30.75	23.37
Remaining healthy:	31.78	32.26	45.93

* Refers to the percent in the sample that went from below to above -1 z-scores.
**Refers to the percent in the sample that went from above to below -1 z-scores.

Figure 1: Distribution of z-scores

China Health and Nutrition Survey

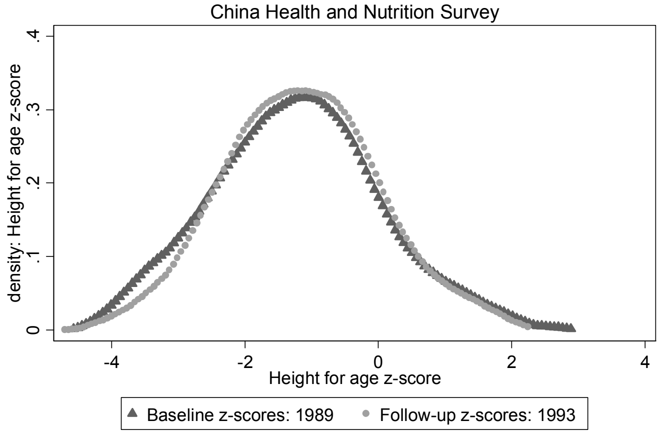

Figure 2: Distribution of z-scores

KwaZulu-Natal Income Dynamics Survey

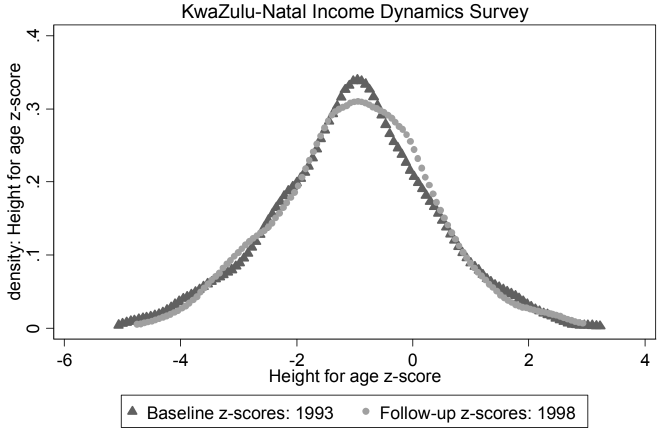

Figure 3: Distribution of z-scores

Nicaraguan Living Standard Measurement Survey

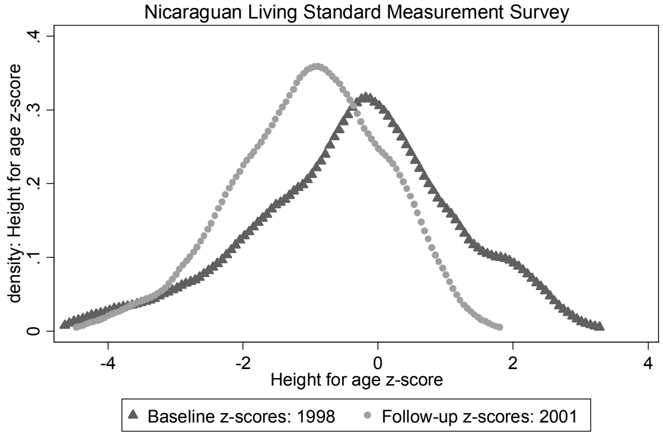

Table 2: Descriptive Statistics of Core Control Variables

	CHNS China (N=1,224)		KIDS South Africa (N=530)		EMNV Nicaragua (N=492)	
	Mean	SD	Mean	SD	Mean	SD
Child Level Variables:						
Age (in years)[1]	7.36	1.88	8.16	1.76	4.03	0.57
Male (=1)	0.55	0.50	0.50	0.50	0.53	0.50
Ethnic indicator (Indian/Indigenous=1)[2]			0.11	0.31	0.03	0.17
Mother's age (in years)	29.48	4.75	30.82	7.09	26.40	7.38
Mother's height (in cm)	155.55	5.56	157.49	4.98	153.17	8.14
Mother's Education < primary (=1)[3]	0.12	0.33	0.46	0.50	0.19	0.39
Missing information on mother (=1)			0.08	0.28	0.02	0.15
Household Level Variables:						
Wealth score	-0.01	0.84	-0.00	0.95	0.00	0.93
Household size	4.95	1.67	8.71	3.72	7.23	3.05
Log of distance to clinic (in min)	-3.00	3.42			0.74	0.92
Missing information on wealth score (=1)	0.05	0.21			0.01	0.11
Community Level Variables:						
Urban (=1)	0.27	0.44	0.09	0.29	0.45	0.49
Metro(=1)			0.16	0.37		
Log of mean wages (unskilled labor):	0.73	2.77				

*All variables are reported for the baseline, unless otherwise indicated.

[1]Age is reported here for the follow up survey, age in the baseline is included as dummy variables.

[2] The Indian indicator is used in KIDS, the Indigenous used in LSMS.

[3] The indicator for "low mother's education" varies by data set depending on the distribution of schooling. For CHNS it is defined as partial primary or less, for KIDS it is defined as primary education or lower, for EMNV it is defined as the mother being illiterate.

Table 3: Summary coefficients of lagged height for age z-scores on current z-score

	CHNS : China (N=1,224)		KIDS : South Africa (N=530)		LSMS : Nicaragua (N=492)	
	OLS	Instrumented	OLS	Instrumented	OLS	Instrumented
Full Sample coefficient	0.42***	0.25***	0.28***	0.24*	0.39***	0.22**
Standard error	(0.032)	(0.084)	(0.045)	(0.13)	(0.045)	(0.10)
R-squared	0.40	0.24	0.21	0.14	0.41	0.21
Reduced sample coefficient (haz<-1)	0.43***	0.35*	0.20*	0.19	0.23*	0.19
Standard error	(0.052)	(0.18)	(0.11)	(0.21)	(0.17)	(0.25)
R-squared	0.26	0.17	0.18	0.17	0.29	0.26
Full Sample using height in cms.	0.58***	0.075**	0.44***	0.24***	0.60***	0.21***
Standard error	(0.043)	(0.032)	(0.042)	(0.041)	(0.063)	(0.058)
R-squared	0.84	0.79	0.68	0.62	0.68	0.53

*denotes statistical significance at the 10% level, ** at the 5% level and *** at the 1% level. Standard errors for the IV models are bootstrapped. Full regression results presented in the Appendix.

Table 4: Interactions among lagged height and family and environmental factors

Data:	CHNS : China		KIDS : South Africa		LSMS : Nicaragua	
Sample	Full	HAZ≤-1	Full	HAZ≤-1	Full	HAZ≤-1
Interaction if lagged height with:						
Maternal education	-0.243	-0.420**	0.346*	-0.250	0.180	0.415
(t-statistic)	(1.52)	(2.36)	(1.72)	(0.60)	(1.15)	(0.82)
Maternal height	0.009	0.052**	-0.004	-0.010	0.007**	-0.018**
(t-statistic)	(0.01)	(2.04)	(0.27)	(0.35)	(3.11)	(4.37)
Household wealth index	0.230**	0.470**	-0.12	-0.500**	-0.017	-0.590**
(t-statistic)	(2.73)	(2.99)	(0.94)	(2.05)	(0.33)	(2.60)
Distance to nearest health facility	0.023	0.061			-0.01	-0.12
(t-statistic)	(1.57)	(1.53)			(0.10)	(0.51)
Male	0.001	0.031	-0.226	-0.350	0.119	-0.240
(t-statistic)	(0.01)	(0.13)	(1.08)	(0.98)	(1.12)	(0.57)

** (*) indicates significance at 5 (10) percent confidence level. T-statistics based on bootstrapped standard errors. Lagged height and its interaction treated as endogenous.

Appendix

Table 1A: Stage 1 Results Predicting Baseline Height for Age

	CHNS : China (N=1,224)		KIDS : South Africa (N=530)		ENMV : Nicaragua (N=492)	
	Coefficient	SE	Coefficient	SE	Coefficient	SE
Constant	-7.43***	(1.21)	-0.011	(2.947)	0.32	(3.25)
Child Level Variables:						
Age spline (omitted is 0-6 months):						
6-12 months (=1)	-0.85***	(0.21)	-0.72**	(0.30)	-0.77***	(0.57)
13-24 months (=1)	-1.39***	(0.19)	-1.15***	(0.24)	-1.67***	(0.13)
25-60 months (=1)	-1.52***	(0.17)	-0.93***	(0.23)		
61+ months (=1)	-1.72***	(0.16)	-0.96***	(0.23)		
Male (=1)	0.0062	(0.0625)	-0.15	(0.12)	-0.32***	(0.12)
Ethnic indicator (Indian/Indigenous=1)[1]			0.42	(0.52)	-0.50*	(0.29)
Mother's age (in years)	0.0022	(0.0074)	-0.0098	(0.0098)	0.0048	(0.0092)
Mother's height (in cm)	0.044***	(0.007)	0.00019	(0.01705)	0.023***	(0.008)
Mother's Education < primary (=1)[2]	-0.18*	(0.11)	-0.057	(0.189)	-0.36**	(0.16)
Missing information on mother (=1)			0.29	(0.26)	0.68*	(0.39)
Household Level Variables:						
Wealth score	0.23***	(0.04)	-0.13	0.21	0.14*	(0.07)
Missing information on wealth score (=1)	0.075	(0.162)			-1.08***	(0.35)
Log of distance to clinic (in min)	0.013	(0.011)			-0.032	(0.062)
Household size	-0.0018	(0.0217)	-0.023	(0.021)	-0.032	(0.019)
Community Level Variables:						
Urban (=1)	0.41	(0.27)	1.27***	(0.44)	0.90***	(0.27)
Metro(=1)			1.02**	(0.44)		
Log of mean wages (unskilled labor):	-0.011	(0.012)				
F-test of sub provinces, districts, departments:	F (14, 176)	= 4.88	F (28, 59)	= 41.39	F (16, 106)	= 4.58
	Prob > F	= 0.000	Prob > F	= 0.000	Prob > F	= 0.000
F-test of prices	F (9, 176)	= 2.85	F (7, 59)	= 5.50	F (9, 106)	= 6.00
	Prob > F	= 0.004	Prob > F	= 0.000	Prob > F	= 0.000
R - squared		= 0.29		= 0.20		= 0.36

List of price basket used to identify height for age:
CHNS (1989) : (1) rice; (2) noodles; (3) powdered milk; (4) sugar; (5) eggs; (6) cabbage; (7) vegetables; (8) beef; (9) coal.
KIDS (1993) : (1) formula; (2) fresh milk; (3) rice; (4) potatoes; (5) eggs; (6) maize; (7) soap.
EMNV (1998): (1) rice; (2) corn; (3) plantain; (4) potato; (5) fresh milk; (6) sugar; (7) vinegar; (8)beef; (9) soap.

*denotes statistical significance at the 10% level, ** at the 5% level and *** at the 1% level.
All SE are robust, clustered on the community level.
[1] the East Indian indicator is used in KIDS, the Indigenous Indian indicator is used in EMNV
[2] The indicator for 'low mother's education' varies by data set, meant to capture the same concept. For CHNS it is defined as partial primary or under, for KIDS it is defined as primary education or lower, for EMNV it is defined as illiteracy.

Table 2A: Stage 2 Height for age estimates for China Health and Nutrition Survey

	Naïve Estimates (N = 1,224)		Instrumented Estimates (N = 1,224)	
	Coefficient	SE	Coefficient	SE
Constant	-6.42	(1.21)	-7.71	(1.14)
Lagged Height for age z-score	0.42***	(0.032)	0.24***	(0.084)
Child Level Variables:				
Age (years)	0.019	(0.016)	-0.011	(0.018)
Male (=1)	0.086*	(0.049)	0.086	(0.054)
Mother's age (in years)	0.0028	(0.0061)	0.0027	(0.0058)
Mother's height (in cm)	0.034***	(0.0077)	0.041***	(0.0069)
Mother's Education < primary (=1)	-0.0079	(0.069)	-0.041	(0.092)
Household Level Variables:				
Wealth score	0.19***	(0.045)	0.24***	(0.046)
Missing information on wealth score (=1)	-0.071	(0.12)	0.049	(0.12)
Log of distance to clinic (in min)	-0.0011	(0.011)	0.00069	(0.0090)
Household size	-0.013	(0.021)	-0.011	(0.019)
Community Level Variables:				
Urban (=1)	0.0012	(0.083)	0.0074	(0.070)
Log of mean wages (unskilled labor):	0.044*	(0.025)	0.068*	(0.035)
F-test of provinces:	F (14, 176)	= 1.78	F (7, 176)	= 1.94
	Prob > F	= 0.093	Prob > F	= 0.065
F-test of prices	F (9, 176)	= 2.65	F (9, 176)	= 1.44
	Prob > F	= 0.007	Prob > F	= 0.175
R - squared		0.39		0.24
Test of endogeneity *(HÂZ):*	-0.16*	(.09)		
Test of exclusion restrictions, p-values:	1989	= 0.072		
	1993	= 0.000		

List of prices: (1) rice; (2) noodles; (3) sugar; (4) eggs; (5)cabbage; (6) vegetables; (7) powdered milk; (8) beef; (9) coal.

*denotes statistical significance at the 10% level, ** at the 5% level and *** at the 1% level.

Reported SE are robust, clustered on the community level.

Estimates for the Instrumented model are bootstrapped.

Table 3A: Stage 2 Height for age estimates for KwaZulu-Natal Income Dynamics Survey

	Naïve Estimates (N= 530)		Instrumented Estimates (N= 530)	
	Coefficient	SE	Coefficient	SE
Constant	-3.79	(2.03)	-3.71	(1.97)
Lagged Height for age z-score	0.28***	(0.29)	0.25*	(0.13)
Child Level Variables:				
Age (years)	-0.10***	(0.029)	-0.097***	(0.031)
Male (=1)	0.091	(0.096)	0.087	(0.11)
East Indian (=1)	0.99***	(0.24)	0.96***	(0.28)
Mother's age (in years)	-0.0015	(0.0070)	-0.0025	(0.0076)
Mother's height (in cm)	0.028**	(0.012)	0.027**	(0.011)
Mother's Education <= primary (=1)	0.061	(0.14)	0.064	(0.12)
Missing information on mother (=1)	-0.22	(0.24)	-0.19	(0.23)
Household Level Variables:				
Wealth score	0.0039	(0.18)	0.039	(0.15)
Household size	0.020	(0.013)	0.019	(0.013)
Community Level Variables:				
Urban (=1)	0.38	(0.46)	0.35	(0.35)
Metro(=1)	0.15	(0.33)	0.13	(0.29)
KwaZulu province (=1)	0.43*	(0.24)	0.41	(0.26)
F-test of prices	F (7, 59)	= 3.90	F (7, 59)	= 2.95
	Prob > F	= 0.002	Prob > F	= 0.010
R - squared		0.21		0.14
Test of endogeneity *(HÂZ):*	-0.036	(0.12)		
Test of exclusion restrictions, p-values:	1993 prices	= 0.084		
	1998 prices	= 0.000		

List of prices: (1) fresh milk; (2) bread; (3) sugar; (4) margarine; (5) cabbage; (6) bean; (7) washing powder.

*denotes statistical significance at the 10% level, ** at the 5% level and *** at the 1% level.

Reported SE are robust, clustered on the community level.

Estimates for the Instrumented model are bootstrapped.

Table 4A: Stage 2 Height for age estimates for Nicaraguan EMNV

	Naïve Estimates (N=492)		Instrumented Estimates (N=492)	
	Coefficient	SE	Coefficient	SE
Constant			-4.06	(1.89)
Lagged Height for age z-score	0.39***	(0.045)	0.22**	(0.10)
Child Level Variables:				
Age (years):	0.42***	(0.090)	0.25*	(0.14)
Male (=1)	-0.12	(0.092)	-0.17**	(0.086)
Indigenous Indian (=1)	-0.55	(0.37)	-0.70*	(0.39)
Mother's age (in years)	0.0014	(0.0051)	0.0019	(0.0059)
Mother's height (in cm)	0.0085	(0.0084)	0.13***	(0.011)
Mother Illiterate (=1)	0.080	(0.10)	-0.0052	(0.13)
Missing information on mother (=1)	-0.14	(0.35)	-0.047	(0.46)
Household Level Variables:				
Wealth score	0.27***	(0.052)	0.31***	(0.053)
Log of distance to clinic (in min)	0.17	(0.041)	0.032	(0.051)
Household size	-0.021	(0.015)	-0.027	(0.15)
Community Level Variables:				
Urban (=1)	-0.079	(0.17)	-0.10	(0.18)
Central Urbano Region (=1)	1.03***	(0.30)	1.08***	(0.40)
Managua Region (=1):	0.48**	(0.24)	0.47**	(0.24)
Pacifico Rural Region (=1):	0.13	(0.17)	0.095	(0.20)
F-test of prices	F (7, 147)	= 3.58	F (7, 147)	= 2.56
	Prob > F	= 0.001	Prob > F	= 0.016
F-test of region	F (7, 147)	= 4.78	F (7, 147)	= 3.51
(omitted is Pacifico Urbano Region):	Prob > F	= 0.003	Prob > F	= 0.017
R - squared		0.41		0.21
Test of endogeneity *(HÂZ):*	-0.21*	(0.11)		
Test of exclusion restrictions, p-values:	1998 prices	= 0.269		
	2001 prices	= 0.009		

List of prices: (1) corn; (2) fresh milk; (3) plantain; (4) orange; (5) bread; (6) chicken; (7) salt.
*denotes statistical significance at the 10% level, ** at the 5% level and *** at the 1% level.
Reported SE are robust, clustered on the community level.
Estimates for the Instrumented model are bootstrapped.

Table 5A: Variables used in Principal Component Analysis of Wealth Score

	CHNS : China (N=1,224)	KIDS : South Africa (N=530)	LSMS : Nicaragua (N=492)
(1)	Television (=1)	Flush Toilet (=1)	Number of rooms
(2)	Piped water (=1)	Piped water (=1)	Electricity (=1)
(3)	Per capita income (Yuan)	Refrigerator (=1)	Television (=1)
(4)	Radio (=1)	Telephone (=1)	Stove (=1)
(5)	Interior toilet (=1)	Per capita expenditure (Rand)	Electric fan (=1)
(6)	Electricity (=1)	Electricity (=1)	Refrigerator (=1)
(7)	VCR (=1)	Radio (=1)	Iron (=1)
(8)	Bicycle (=1)	Bicycle (=1)	Piped water (=1)
(9)	Scooter/motorbike (=1)		Per capita income (Cordoba)
(10)	Car (=1)		Non-dirt floor (=1)
(11)	Sheep (=1)		VCR (=1)
(12)	Chicken (=1)		Sewing machine (=1)
(13)	Horse (=1)		Flush toilet (=1)
(14)	Pig (=1)		Bicycle (=1)
(15)			Car (=1)
(16)			Toaster (=1)
(17)			Oven (=1)
(18)			Scooter/motorbike (=1)
(19)			Washing machine (=1)
(20)			Radio (=1)

* Principle components are listed in order of their contribution to the score in the baseline, where higher contributing variables are listed first.

** Income and expenditure are reported on a monthly adjusted basis.