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Does Famine Matter for Aggregate Adolescent Human Captial Acquisition in Sub-Saharan Africa?

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Abstract

To the extent that in utero and childhood malnutrition negatively affects later stage mental and physical health, it can possibly constrain later stage human capital acquisition, which is an important driver of economic growth. This paper considers the impact of famine on aggregate adolescent human capital formation in Sub-Saharan Africa. We parameterize a joint adolescent human capital and food nutrition production function to estimate the effects of famine on primary school completion rates of individuals age 15 - 19. Mixed fixed and random coefficient parameter estimates for 32 Sub-Saharan African countries between 1980 - 2010 reveal that primary school completion rates of adolescents are proportional to the quantity of food and nutrition produced during childhood and in utero. This suggests that declines in food production and nutrition associated with famine in Sub-Saharan Africa have large negative effects on the acquisition of human capital by adolescents and on long-run material living standards. Our findings also suggest that policy makers in Sub-Saharan Africa should prioritize food security policies that prevent food shortages and famines, which would increase long-run economic growth and material living standards.

JEL Classification: C33, I15, I25, O10, O15, O55, Q18

Key Words: Human Capital, Famine, Nutrition, Sub-Saharan Africa

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Highlights

- We parameterize a joint adolescent human capital and food nutrition production function to

estimate the effects of famine on primary school completion rates of individuals age 15 - 19.

- Random effects parameter estimates for 32 Sub-Saharan African countries between 1980 - 2010

reveal that primary school completion rates of adolescents are proportional to the quantity of
food and nutrition produced during childhood and in utero.

- The results suggest that declines in food production and nutrition associated with famine in

Sub-Saharan Africa have large negative effects on the acquisition of human capital by adolescents and on long-run material living standards.

1 Introduction

Starting in the 1980's the economic analysis of famines has captured increasing attention in the theoretical and empirical economic development literature (Cormac, 2007; Ravallion, 1997). An important strand of this literature emphasizes the link between famine and the long-term health and economic outcomes of famine survivors.[1] Barker, 1990; and Barker and Godfrey, 2000; are credited for providing the main research solidifying the premise that a shock in utero or very early in childhood has long lasting effects on survivors. A central idea has been that childhood malnutrition due to food insecurity and famine negatively affects later stage adult health, cognitive ability and economic outcomes. For example, in the case of China, exposure to famine during childhood has been found to decrease adult stature and labor market earnings (Chen and Zhou, 2007), educational attainment and wealth (Shi, 2011), adult literacy (Luo, Mu, and Zhang, 2006; Mu and Zhang, 2011), and labor supply (Meng and Qian, 2006; Luo, Mu, and Zhang, 2006). Sub-Saharan Africa (henceforth, SSA) appears to be the region in the world most vulnerable to famine and food insecurity in the 21st century (Baro and Deubel, 2006; Muller and Krawinkel, 2005; Devereux, 2009; Vanhaute, 2011).

Indeed, SSA is the only sub-continent in the 21st century that has experienced, and continues to experience, mass mortality due to food crisis, with four countries: Ethiopia in 2000, Malawi in 2002, Niger in 2005, and Somalia in 2011,

[1] A relatively new strand of the literature considers the childhood nutrition-human capital-economic growth nexus. See for instance, Field et. al (2009) and Alderman et. al (2003).

officially attaining the stage of famine.[2] In this context it is surprising that given evidence that childhood malnutrition constrains adult human capital (Maccini and Yang, 2009; Schultz, 1999; Victora et. al, 2008), which appears to be an important driver of economic growth in SSA (Gyimah-Brempong and Wilson, 2004; Gyimah-Brempong, Paddison, and Mitiku, 2006), to date the empirical development literature has only considered—as far as we can determine—the causes and/or consequences of famine and food insecurity on human capital in Ethiopia (Dercon, 2004; Dercon and Hoddinott, 2005; Dercon and Porter, 2010), Tanzania (Alderman, Hoogeveen, and Rossi, 2006; 2009) and Zimbabwe (Alderman, Hoddinott, and Kinsey, 2006). A related study by Field et. al (2009) examines the impact of iodine deficiency - a core micronutrient - on schooling attainment in Tanzania. Unsurprisingly, most of these previous studies have approached the topic from a microeconomic perspective.

In this paper, we depart from the tradition in the literature by considering the impact of famine during childhood and during birth (in utero) on aggregate adolescent human capital acquisition in SSA.[3] Our approach is indirect, as we exploit cross-country variation in food production, from which childhood nutrition must be derived, to estimate the human capital effects of declines in food production and nutrition associated with famine on adolescent/young adult human capital.[4] As food productivity appears to be a major catalyst of modern economic growth over the past 300 years, and food supply and production in SSA is low relative to the rest of the world (Fogel, 2004), our analysis will inform the extent to which food production and famine in SSA has consequences for an important driver of economic growth—human capital (Gyimah-Brempong and Wilson, 2004; Gyimah-Brempong, Paddison, and Mitiku, 2006). Indeed, given evidence that constrained access to nutrition in-utero and during early childhood appears to constrain schooling outcomes and adult labor market productivity in developing countries (Hoddinott et. al, 2008; Neelsen and Stratmann, 2011), our implied childhood/in utero nutrition-adult productivity causal nexus is appropriate as improved nutrition appears to have favorable consequences for long-term economic growth by enhancing the capacity of individuals to benefit from education (Fogel, 2004).

Our inquiry makes at least three contributions. First, our analysis contributes to a broad and growing literature on the economic consequences of nutrition for human welfare and material living standards (Steckel 2009). In particular, our analysis will inform the extent to which material living stan-

[2] A chronicle of major 20th century famines is also consistent with a greater vulnerability of SSA. Devereux (2000) reports that between 1903 - 1999, 32 major global famines occurred in which there was excess mortality. Of these major famines, a disproportionate number—approximately 56 percent—were in SSA.

[3] Adolescents constitute nearly one-third of SSA's population and this age group is also the most affected by disease, unemployment and poverty. Thus, a study of factors affecting aggregate adolescent human capital formation in the context of SSA carries important implications for policy.

[4] This is evidenced by the fact that three of the most recent famines in SSA—Ethiopia, Malawi and Niger —were triggered by a moderate decline in crop and/or livestock production (Devereux, 2009).

dards in SSA can be explained by the so-called *Technophysical evolution*, the process in which human living standards are raised by improvements in nutrition through its contribution to robust human physiology which enables more work effort—which in turn increases labor productivity (Fogel, 2004; Fogel and Costa, 2009). Second, as our specification of adolescent human capital recognizes country-specific heterogeneity, we add to the literature on estimating cross-country panel relationships in the presence of parameter heterogeneity (Brock and Durlauf, 2001; Eberhardt and Teal, 2011; Hineline, 2008). Last but not least, our inquiry contributes to the literature that considers the consequences of food and nutrition for economic growth and human welfare in SSA. In our theoretical framework, food can be viewed as an input into nutritional status, which is related to economic growth in SSA (Drechsel et. al, 2001; Moradi, 2008). As such, we link nutritional status derived from food production to human capital acquisition, which appears to be an important driver of economic growth in SSA (Gyimah-Brempong and Wilson, 2004; Gyimah-Brempong, Paddison, and Mitiku, 2006).

The remainder of this paper is organized as follows. In the second section we provide a theoretical framework for considering the effects of childhood nutrition derived from food supply on adolescent human capital in terms of primary education outcomes. Adolescent human capital outcomes and childhood/in utero nutrition are viewed as joint outputs. The third section discusses the data and empirical methodology. As the efficacy of producing nutrition in the food supply is country-specific, we estimate the parameters of a joint adolescent human capital and food nutrition production function for SSA with a mixed fixed and random coefficient estimator. In the fourth section, we report and discuss parameter estimates. The last section concludes.

2 The Production of Human Capital, Food and Nutrition

Our theoretical framework views childhood nutrition and adolescent human capital as jointly determined.[5] In particular, as the childhood nutrition required for optimal development into adolescence is derived from food consumption, food production during childhood and adolescent human capital are joint outputs.[6] As there is a time lag between childhood and adolescence, we posit that for a given country i, an aggregate production function exists that jointly produces at time T adolescent human capital $H_{i,T}$, and at time $T-l$, where l is some lag, childhood nutrition derived from a stock of food $F_{i,T-l}$.[7] Both $H_{i,T}$ and $F_{i,T-l}$

[5] This is consistent with microeconomic behavioral models linking nutritional status, productivity and growth, as in Alderman et. al (2003), Behrman and Deolalikar (1988), Strauss and Thomas (1998) and Baez et. al (2010).

[6] We abstract from the fact that maternal health conditions during pregnancy may also significantly affect child cognitive and mental development (Coneus, Laucht, and ReuB, 2012; and Nikolov, 2012), which in turn affects later stage human capital outcomes.

[7] We discount for the time being, the effect of food imports on nutrition and only focus on nutrition derived from home produced food stock as measured by the Food Production

are produced with a production function $G(K_{i,T-l}, L_{i,T-l})$, where $K_{i,T-l}$ and $L_{i,T-l}$ are the stock of capital and labor respectively at time $T-l$.[8]

Each country is assumed to have some control over the concentration of nutrition in its food supply, and can make a choice about the quantity of nutrition in food, and allocates a fraction λ of its inputs to producing nutritional content in the produced food supply.[9] Thus for country i, the joint production technology is $F_{i,T-l} = \phi(\lambda)G(K_{i,T-l}, L_{i,T-l})$, $H_{i,T} = (1 - \lambda)G(K_{i,T-l}, L_{i,T-l})$. In a manner similar to the literature on pollution abatement (Dean, Lovely, and Wang, 2009; Copeland and Taylor, 2003), we assume that the relation between the production of food and the concentration of nutrition in the food is of the form $\phi(\lambda) = (1 - \lambda)^{1/c_i}$, where $0 \leq c_i \leq 1$. The parameter c_i is for country i, a measure of how effective it is in enabling nutrition, as measured by the nutrition content (c_i) in food supply. As c_i increases, the food supply provides more nutrition per unit of food produced.

Inverting on $\phi(\lambda)$ and solving for $H_{i,T}$ yields $H_{i,T} = (F_{i,T-l})^{c_i}[G(K_{i,T-l}, L_{i,T-l})]^{1-c_i}$, which is a net joint production function for adolescent human capital. Thus for country i at time T, the stock of adolescent human capital is a function of the food supply at time $T-l$ and for $c_i < 1$, the stock of capital and labor at time $T-l$. If we assume $G(\cdot) = A_{T-l}K^{\alpha}_{T-l}L^{1-\alpha}_{T-l}$, for $0 < \alpha < 1$, $A_{T-l} = A_o e^{rT-l}$, $L_{T-l} = L_o e^{gT-l}$, $\ln A_o = d + \zeta_{i,T}$, $rT - 1 = e + \eta_{i,T}$, $\ln L_o = f + \upsilon_{i,T}$, where d, e and f are constants,r is the growth rate of technology, g is the population growth rate, and $\zeta_{i,T}$, $\eta_{i,T}$ and $\upsilon_{i,T}$ are error terms, a tractable econometric specification of the adolescent human capital net production function is:

$$logH_{i,T} = \beta_o + \beta_1 logF_{i,T-l} + \beta_2 logK_{i,T-l} + \beta_3 loggT - l + \varepsilon_{i,T} \qquad (1)$$

where $\beta_o = (1 - c_i)[(d + e) + (1 - \alpha)f]$, $\beta_1 = c_i$, $\beta_2 = (1 - c_i)\alpha$, $\beta_3 = (1 - c_i)(1 - \alpha)$, and $\varepsilon_{i,T} = \zeta_{i,T} + \eta_{i,T} + \upsilon_{i,T}$.[10]

Index. In any case, humanitarian emergency food relief most frequently arrives only after a famine—a decline in the food production index—has been announced.

[8] The assumption that adolescent human capital is produced with a lag is consistent with the empirical evidence suggesting that critical brain development in children typically occurs prior to adolescence (Gale et. al, 2004).

[9] This is an important assumption to the extent that food production (or supply) might diverge substantially from food availability on the one hand, and nutritional content on the other hand that is potentially important for the cognitive development of children (Demment, Young, and Sensenig, 2003). In particular our characterization of c_i follows that of the pollution abatement literature (See for example Dean, Lovely and Wang, 2009) in which a country can invest resources to abate the absence of nutrition in produced food. As a country becomes more effective at increasing the nutritional content of food, c_i increases, and the food supply becomes an increasingly more important determinant of human capital acquisition. Our random parameter estimation framework below recognizes the possibility that countries differ in their capabilities at enabling nutrition in food supply and in ensuring efficient country-wide distribution of food supply.

[10] This specification follows from assuming that technological change is disembodied, and for each country, similar to Mankiw, Romer, and Weil (1992), the initial level of technology (A_o) and its growth rate (rt) respectively are determined by a constant—d and e respectively—plus unobserved country-specific factors $\zeta_{i,T}$ $\eta_{i,T}$, and $\upsilon_{i,T}$ respectively.

3 Data and Methodology

To estimate the parameters of the adolescent human capital production function, we utilize *World Development Indicators* (2010) data for SSA.[11] Our dependent variable - which is measured in 5 year intervals - is average years of primary schooling completed for the total population (including females) aged 15 - 19 (Barro and Lee, 2010). Primary schooling consists of the first 5 - 7 years of formal schooling approximately. We classify this age group as consisting of adolescents as it constitutes a closed interval of individuals which allows us to empirically measure the food production and factor input conditions they faced during childhood. This definition of adolescence is consistent with the official definition of this age group utilized by the *World Health Organization* (2005) - the age interval of 10 to 19 years. However we depart from the *World Health Organization* definition of childhood - the age interval of birth to 9 years. Instead we follow a convention that approximates that of Shahar et. al (2005) and define childhood as the age interval between birth and 12 years of age.[12]

The theoretical specification in (1) above links current adolescent human capital to food and nutrition supply during childhood, which implies a lag structure. As adolescent human capital presumably reflects the cumulative effects of nutritional intake throughout childhood [13], the lag structure of food supply [14] and factor input conditions should also be cumulative, and our empirical strategy aims to approximate this. We estimate two specifications with three different measures of the food and factor input supply. The first one measures the food supply and factor input conditions faced during our broad measure of childhood. We use from the *World Development Indicators* (2010) reported value of the Food Production Index, Gross Capital Formation, and a derived Growth Rate of the Population. In each instance, we average the independent variables across the years in which the adolescents in each country were children. For each adolescent age endpoint in the Barro-Lee measure of primary school completion, the averaging of independent variables for each year was from birth to 12 years of age.[15] Our second specification captures the food supply and factor conditions adolescents faced between birth and five years of age - an age interval that approximates a critical period of brain development in children (Gale et. al, 2004; Rosales, Reznick, and Zeisel, 2009). Our last specification uses the food supply adolescents faced at birth - the 15 and 19 year lag of the food production index. This allows us to consider famine and the "Fetal Origins

[11] *World Development Indicators* data are available at http://data.worldbank.org/data-catalog/world-development-indicators.

[12] Shahar et. al (2003) treat adolescence as starting at approximately age 15 and ending at age 18.

[13] This is consistent with Baez et. al (2010) approach which views human capital as a cumulative process of education and skills, including key inputs such as the nutritional and health status of individuals, developed over the early stages of life until adolescence.

[14] Rather than growth in the Food Production Index, an alternative approach consists of considering the impacts of serious weather-induced production shortfalls on subsequent primary school attainment. The idea being to see if exogenous variation in agricultural production presages a change in primary school attainment.

[15] This definition of childhood years is similar to that used by Shahar et. al (2003).

Hypothesis" (Almond and Currie, 2011; Barker, 1990) in SSA - the extent to which famine experienced *in utero* constrains the acquisition of human capital later in life.

As our theoretical specification in (1) above implies a country-specific intercept and parameter coefficients - all are a function of a country's effectiveness at producing nutrition in the food supply (c_i)$-$ we estimate the parameters of the adolescent human capital specification within a mixed fixed and random coefficient framework (Laird and Ware, 1982; Rabe-Hesketh and Skrondal, 2008):

$$\mathbf{H} = \mathbf{X}\boldsymbol{\beta} + \mathbf{Z}\mathbf{u} + \boldsymbol{\varepsilon}$$

with $\mathbf{Var}[\mathbf{u}] = \mathbf{G}$, $\mathbf{Var}[\boldsymbol{\varepsilon}] = \boldsymbol{\sigma}_{\boldsymbol{\varepsilon}}^2 \mathbf{R}$, where $\mathbf{G}$ is the variance-covariance matrix of variance components, $\boldsymbol{\sigma}_{\boldsymbol{\varepsilon}}^2$ is the residual error vector, $\mathbf{R}$ is a matrix of residual variance parameters, $\boldsymbol{\sigma}_{\boldsymbol{\varepsilon}}^2 \mathbf{R}$ is the variance-covariance matrix of residual variance parameters, $\mathbf{H}$ is an $N \times 1$ vector of adolescent human capital measurements for country i, $\mathbf{X}$ is the $N \times p$ fixed-effects design matrix of exogenous variables, $\boldsymbol{\beta}$ is the $p \times 1$ vector of fixed coefficients, $\mathbf{Z}$ is the $N \times q$ random-effects design matrix, $\mathbf{u}$ is the $q \times 1$ vector of random coefficients, and $\boldsymbol{\varepsilon}$ is the $N \times 1$ vector of random errors.

Our mixed fixed and random coefficient specification explicitly recognizes the unbalancedness of our dependent variable across time and cross-country heterogeneity in the effects of the exogenous variables on adolescent human capital acquisition in SSA.[16] Given the plausibility of parameter heterogeneity in general in cross-country econometric specifications of the level and growth of economic variables (Brock and Durlauf, 2001; Eberhardt and Teal, 2011; Hineline, 2008), our mixed coefficient estimator enables better identification of the effects of the hypothesized endogenous variables on adolescent human capital acquisition in SSA. Our mixed coefficient estimator also allows a consideration of parameter heterogeneity that is caused by cross-sectional dependence within and across countries who may share similarities with respect to say history, geography, and climate (Eberhardt and Teal, 2011) - which is also a source of bias in parameter estimates - through plausible and identifiable specifications of $\mathbf{Var}[\mathbf{u}]$ and $\mathbf{Var}[\boldsymbol{\varepsilon}]$.

The adolescent human capital acquisition specification in (1) explains aggregate economy-wide outcomes and may obscure the fact that at the individual microeconomic level, the choice of $H_{i,T}$ follows from the optimizing agents solving a decision problem. In this context, our aggregate macroeconomic approach to adolescent human capital acquisition may provide biased parameter estimates

[16] Our dependent variable is measured in 5 year intervals, resulting in gaps or missing year observations for countries. In a mixed coefficient specification this can cause a proliferation of variance parameters making identification difficult. We use the mixed coefficient estimator in *STATA 11.0* provided by the xtmixed program, which accommodates unobserved random parameters by utilizing an Expectation Maximization (EM) algorithm (Dempster, Laird, and Rubin, 1977; Laird and Ware, 1982;) for estimating parameters. In general, EM algorithms ensure convergence to the true parameter space conditional upon the observed data (Van Dyk, 2000), and useful whenever data have missing observations, and/or when there are additional but unobserved parameters (e.g. random coefficients).

as a result of model misspecification - a source of which could be unobserved heterogeneity at the individual level. However, our single equation aggregate macroeconomic specification has significant virtue. To the extent that our specification constitutes a sensible and/or approximate long-run equilibrium relationship between adolescent human capital acquisition and food/nutrition, parameter estimates will capture the equilibrium responses of all agents in Sub-Saharan African economies. Indeed, viewed from the requirements of identifying long-run equilibrium relationships with single aggregate macroeconomic equations - particularly the inclusion of exogenous lagged variables as independent regressors (Phillips and Loretan, 1991) - our macroeconomic single-equation specification of adolescent human capital acquisition satisfies the exogeneity criterion on dependent variables for parameter identification in aggregate single-equation models articulated by Hendry and Richard (1982, 1983.)

4 Results

Table 1 reports a covariate summary for our sample of SSA countries. Given the covariates of interest in our analysis, our sample resulted in a total of 186 paneled observations consisting of 32 SSA countries over the 1980 - 2010 time period. Below, our parameter estimates are across three specifications of the food supply and factor input conditions - during childhood, between birth and age 5, and during birth. As such the lag structure of the food/nutrition supply and factor inputs change, and the covariates are averaged across different lags. Given the time period lags in our required variables, the number of observations decreased to 182 when the food supply and factor covariates are measured during the birth year of the adolescents captured in our dependent variable - average years of primary schooling completed for those aged 15 - 19.

We report mixed coefficient parameter estimates on a log-transformed specification in Tables 2 - 3. The results in Table 2 are based on a specification of the covariates for food/nutrition supply and factor inputs for the childhood years. Table 3 reports results for a specification of the covariates for food/nutrition and factor inputs for the birth year (in utero). In each case we report parameters based on variance-covariance and residual error specifications (e.g. the specification of $\mathbf{Var}[\mathbf{u}]$ and $\mathbf{Var}[\boldsymbol{\varepsilon}]$ respectively) that would at least identify the fixed component of the parameters.[17] As our specification imposes a random

[17] For the structure of $\mathbf{Var}[\mathbf{u}]$, we were able to identify the following structures: *Exchangeable* (Equal variance for random effects, and one common pairwise variance), *Identity* (Equal variance for random effect with zero covariances), *Independent* (One unique variance per random effect with zero covariances), and *Unstructured* (Unique variances/covariances). For the structure of $\mathbf{Var}[\boldsymbol{\varepsilon}]$ we were able to identify the following structures: *Exchangeable* (Common within-group error variance and one common pairwise error covariance), *Exponential*(Correlation between errors is the autoregressive parameter ρ, raised to a power equal to the absolute value of the difference between errors—a generalization of an autoregressive of degree 1 process) *Independent* (Independent and identically distributed errors with one common pairwise error covariance), and *Unstructured* (Unique variances for each within-group error and unique covariances for each within-group error pair). "Able to identify" means achieving converged random effects parameter estimates.

intercept and coefficient for each covariate, we indicate by *Yes* or *No* whether or not all the random coefficients/effects parameters are significant.

Two diagnostic measures are reported to assess the adequacy of our parameter estimates. A chi-square distributed likelihood ratio test against a fixed effects Ordinary Least Squares (OLS) linear regression specification is reported to assess the relative merit of fixed vs. random coefficients. We also report the Bayesian Information Criterion. A minimum Bayesian Information Criterion test statistic (BIC) enables selection of the best specification in terms of minimum description length (Rissanen, 1978) - the specification that captures the most regularity of the data given uncertainty about the true specification.

To enable an assessment of the practical significance of our estimated parameters, we report both the marginal effect of famine on adolescent human capital, and the years of primary schooling lost due to one year of famine based on the predicted random effects parameters evaluated at the sample means. Our definition of famine is defined as an annual 33 percent drop in food production, based on the conservative lower end of crop failure percentage that informed the 19th Century Indian Famine Codes (Howe and Devereux, 2004).[18]

Table 2 reports parameter estimates across 8 identifiable specifications of adolescent human capital production function for food/nutrition supply and input factor conditions during childhood. The first two specifications are similar and differ in that (2) estimates the standard errors via bootstrapping as we were unable to estimate the standard errors of the mixed coefficient specification in (1).[19] In general, across all the specifications, the likelihood ratio test favors random versus fixed coefficients, and the log of food production during childhood is significant and positive, suggesting that adolescent human capital measured by primary school completion rates for individuals aged 15 - 19 is proportional to the supply of food/nutrition during childhood. Based on the marginal effects, the years of primary schooling lost due to a famine range from 1 to 2.5 years approximately. The BIC suggests that the parameter estimates in specifications (4) and (6) capture the most regularity of the data. For both of these specifications, all the random coefficients are significant, and an annual famine during childhood is associated with a loss of approximately 2.5 years of primary schooling by adolescents.

Table 3 reports parameter estimates across 8 identifiable specifications of adolescent human capital production function for food/nutrition supply and in-

[18] In particular, we evaluate the elasticity of adolescent human capital with respect to the food index at the mean values. Given this elasticity, we compute the number of years of schooling lost based on the percent change in primary years of schooling associated with a 33 percent decrease in the food index. As these estimates are based on the fixed portion of the parameter estimates, they are downwardly biased, given the existence of significant and on average positive random components of the coefficients.

[19] The failure to estimate standard errors in mixed coefficient parameter estimates can result from the sheer complexity of identifying the number of unobserved parameters relative to the size of the data. Bootstrapped standard errors (Efron and Tibshirani, 1986) reduce the computational complexity of estimating standard errors via nonparametric resampling estimation. Our bootstrapped standard error estimates are based on 50 replications of resampling observations with replacement.

put factor conditions during the 0 - 5 age interval. The first two specifications are similar and differ in that (2) estimates the standard errors via bootstrapping as we were unable to estimate the standard errors of the mixed coefficient specification in (1). In general, across all the specifications, the likelihood ratio test favors random versus fixed coefficients, and the log of food production during childhood is significant and positive, suggesting that adolescent human capital measured by primary school completion rates for individuals aged 15 - 19 is proportional to the supply of food/nutrition during the 0 to 5 age interval. Based on the marginal effects, the years of primary schooling lost due to a famine during the 0 to 5 age interval ranges from .42 to 1.19 years approximately. The BIC suggests that the parameter estimates in specification (8) captures the most regularity of the data. For this specification, all the random coefficients are significant, and an annual famine during the 0 to 5 year age interval is associated with a loss of approximately .68 years of primary schooling by adolescents.

To consider the effects of food/nutrition supply in utero, Table 4 replicates the parameter estimation scheme in Table 2 across 8 identifiable specifications of adolescent human capital production function for food/nutrition supply and input factor conditions in utero. As in Table 2, the first two specifications are similar and differ in that (2) estimates the standard errors via bootstrapping as we were unable to estimate the standard errors of the mixed coefficient specification in (1). Across all the specifications the likelihood ratio test favors random versus fixed coefficients, and the log of food production in utero is significant and positive, suggesting that adolescent human capital measured by primary school completion rates for individuals aged 15 - 19 is proportional to the supply of food/nutrition in utero. Based on the marginal effects, approximately one year of primary schooling is lost for a year of famine in utero. The BIC suggests that the parameter estimates in specification (8) captures the most regularity of the data. For the mixed coefficient parameter estimates in (8), all the random coefficients are significant, and an annual famine in utero is associated with a loss of approximately 1.22 years of primary schooling by adolescents.

Overall, the BIC minimum mixed coefficient parameter estimates in Tables 2 - 3 suggest that declines in food/nutrition production associated with famine in utero and during childhood have nontrivial negative effects on adolescent human capital acquisition in SSA. That the adolescent human capital effects of famine during childhood are larger than the effects of famine in utero suggest that the effects of famine in SSA are more severe during the childhood years. Our parameter estimates cohere with evidence that brain and cognitive development during adolescence may be more important relative to its development in utero (Steinberg, 2005). Indeed, Cunha and Heckman (2008) find that inputs into a cognitive production function during the childhood years are more important relative to other stages of life prior to adulthood. In this context, compromised food/nutritional intake in a famine during childhood has larger effects on cognitive ability - which is important for human capital acquisition - relative to a famine experienced in utero.

5 Conclusion

This paper considered the impact of in utero and childhood famine on adolescent human capital acquisition in SSA. We parameterized a joint adolescent human capital and food nutrition production function to estimate the effects of in utero and childhood famine on primary school completion rates of individuals aged 15 - 19. Mixed random and fixed coefficient parameter estimates for 32 SSA countries between 1980 - 2010 reveal that primary school completion rates of adolescents are proportional to the quantity of food and nutrition produced during childhood and in utero. We find that the effects are substantial with for example, an annual famine during childhood and utero reducing human capital acquisition by adolescents of approximately 2.5 and 1.22 years respectively.

These large human capital effects of famine are potentially more dramatic given that human capital is important for the growth of material living standards in SSA. Gyimah-Brempong, Paddison and Mitku (2006) for example find that the elasticity of economic growth with respect to years of education - all types - is approximately .09 in SSA. If we evaluate our estimates of the loss in adolescent human capital associated with an annual famine in utero and during childhood, the corresponding reduction in economic growth in SSA as a result of a famine in utero and during childhood is approximately 3 and 6 percent respectively.[20] Given the existence of a long-run positive trend in growth, our results suggests that over time, famine in SSA lowers economic growth which in turn, reduces long-run material living standards. The implication of this for policy is that SSA should prioritize food security policies that prevent food shortages and famines, which would increase long-run economic growth and material living standards.

One possible major limitation of our analysis is that our mixed coefficient parameter estimates may not be estimating the causal effect of famine on adolescent human capital formation. If our model is misspecified, the assumption that the random parameters are orthogonal to the included regressors need not hold. Of course a Hausman test (Hausman, 1978) for the random coefficients could inform the validity of this assumption. However, given that the Hausman test is not suitable for random parameters that are generated from distributions with many fixed and random parameter values (Freedman, 2007), we can only infer from the likelihood ratio tests against an OLS fixed coefficient specification that our BIC minimum mixed coefficient parameter estimates identify the causal effects of famine in SSA on adolescent human capital acquisition assuming our specification is the true model.

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Table 1
Covariate Summary Human Capital, Food Production, Factor Inputs Sub-Saharan Africa: 1980 2010

Covariate	Mean	Standard Deviation	Number of Observations
Average Years of Primary Schooling Age 15 19, Total: (Barro-Lee (2010))	4.04	1.56	186
Food Production Index During Childhood[1]	76.07	20.17	186
Food Production Index During Childhood: Age 0 5[1]	86.88	22.01	183
Food Production Index During Birth[1]	134.42	41.50	182
Growth Rate of Population[2]	.027	.007	186
Gross Capital Formation[3]	1,250,000000	3,530,000000	186

Notes:

Source: *World Development Indicators*, (2010). World Bank, Washington DC, USA.

Sample Countries: Benin, Botswana, Burundi, Cameroon, Central African Republic, Democratic Republic of Congo, Republic of Congo, Cote d'Ivoire, Equatorial Guinea, Gabon, Gambia, Ghana, Kenya, Lesotho, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Rwanda, Senegal, Sierra Leone, South Africa, Sudan, Swaziland, Tanzania, Togo, Uganda, Zambia, and Zimbabwe.

[1] The Food production index has a base year of 1999 2000, and includes food crops that are considered edible and that contain nutrients. Coffee and tea are excluded because, although edible, they have no nutritional value.

[2] The growth rate of the population is based on the de facto definition of population, which counts all residents regardless of legal status or citizenship—except for refugees not permanently settled in the country of asylum, who are generally considered part of the population of their country of origin. The values shown are midyear estimates.

[3] Gross fixed capital formation includes land improvements (fences, ditches, drains, and so on); plant, machinery, and equipment purchases; and the construction of roads, railways, and the like, including schools, offices, hospitals, private residential dwellings, and commercial and industrial buildings. Data are in constant 2000 U.S. dollars.

Table 2
Mixed Coefficient Parameter Estimates Of Adolescent Human Capital Production Function Sub-Saharan Africa: 1980 2010

Specification:	**(1)**	**(2)**	**(3)**	**(4)**
Regressand: Log of Average Years of Primary Schooling Completed by individuals age 15 19				
Regressors:				
Log of Food Production Index During Childhood	.217 (.067)[a]	.217 (.056)[a]	.226 (.072)[a]	.533 (.179)[a]
Log of Growth Rate of Population During Childhood	.006 (.054)	.006 (.066)	.012 (.051)	.073 (.111)
Log of Gross Capital Formation During Childhood	.151 (.022)[a]	.151 (.023)[a]	.153 (.024)[a]	.120 (.036)a
Constant	-2.62 (.393)[a]	-2.62 (.419)[a]	-2.67 (.416)[a]	-3.14 (.977)[a]
Structure of Variance-Covariance:	Independent	Independent	Identity	Independent
Structure of Residual Errors:	Independent	Independent	Independent	Unstructured
All Random Effects Significant?:	No	No	Yes	Yes
Diagnostics:				
Number of Observations	186	186	186	186
Likelihood Ratio Test vs. Linear Regression:	232.86[a]	232.86[a]	214.54[a]	321.68[a]
Bayesian Information Criterion:	-5.84	20.28	22.93	-37.17
Marginal Effect Of Famine on: Adolescent Human Capital	.243	.243	.254	.614
Years of Primary Schooling Lost Due To One Year Of Famine During Childhood:	.982	.982	1.03	2.48

Notes:

Standard errors in parentheses.
[a] Significant at the .01 level [b] Significant at the .05 level [c] Significant at the .10 level

[1]Famine is defined as an annual 33 percent drop in food production, based on the conservative lower end of crop failure percentage that informed the Indian Famine Codes (Howe and Devereux, 2004).

Table 2—continued
Mixed Coefficient Parameter Estimates Of Adolescent Human Capital Production Function Sub-Saharan Africa: 1980 2010

Specification:	**(5)**	**(6)**	**(7)**	**(8)**
Regressand: Log of Average Years of Primary Schooling Completed by individuals age 15 19				
Regressors:				
Log of Food Production Index During Childhood	.226	.533	.167	.213
	(.072)^a	(.179)^b	(.084)^b	(.090^b
Log of Growth Rate of Population During Childhood	.010	.073	-.067	-.002
	(.051)	(.111)	(.026)^b	(.051)
Log of Gross Capital Formation During Childhood	.153	.120	.112	.145
	(.414)^a	(.036)^a	(.021)^a	(.027)^a
Constant	-2.67	-3.14	-1.83	-2.50
	(.414)^a	(.977)^a	(.462)^a	(.499)^a
Structure of Variance-Covariance:	Exchangeable	Unstructured	Exchangeable	Independent
Structure of Residual Errors:	Independent	Exchangeable	Unstructured	Exponential
All Random Effects Significant?:	Yes	Yes	No	No
Diagnostics:				
Number of Observations	186	186	186	186
Likelihood Ratio Test vs. Linear Regression:	216.14^a	321.68^a	392.22^a	295.40^a
Bayesian Information Criterion:	21.33	-37.17	-13.66	-37.03
Marginal Effect Of Famine on: Adolescent Human Capital	.769	1.86	.537	.721
Years of Primary Schooling Lost Due To One Year Of Famine During Childhood:	1.02	2.48	.716	.961

Notes:

Standard errors in parentheses.
[a] Significant at the .01 level [b] Significant at the .05 level [c] Significant at the .10 level

[1]Famine is defined as an annual 33 percent drop in food production, based on the conservative lower end of crop failure percentage that informed the Indian Famine Codes (Howe and Devereux, 2004).

Table 3
Mixed Coefficient Parameter Estimates Of Adolescent Human Capital Production Function: 1980 2010

Specification:	**(1)**	**(2)**	**(3)**	**(4)**
Regressand: Log of Average Years of Primary Schooling Completed by individuals age 15 19				
Regressors:				
Log of Food Production Index	.285	.285	.289	.425
During Childhood: Age 0 5	(.087)[a]	(.096)[b]	(.084)[a]	(.176)[b]
Log of Growth Rate of Population	-.099	-.099	.-126	-.082
During Childhood: Age 0 5	(.085)	(.080)	(.085)	(.071)
Log of Gross Capital Formation	.144	.144	.145	.142
During Childhood: Age 0 5	(.021)[a]	(.023)[a]	(.022)[a]	(.021)
Constant	-1.63	-1.63	-1.42	-2.29
	(.561)[a]	(.553)[b]	(.554)[b]	(.881)[b]
Structure of Variance-Covariance:	Independent	Independent	Identity	Independent
Structure of Residual Errors:	Independent	Independent	Independent	Unstructured
All Random Effects Significant?:	No	No	Yes	No
Diagnostics:				
Number of Observations	183	183	183	183
Likelihood Ratio Test vs. Linear Regression:	188.40[a]	188.40[a]	179.66[a]	284.48[a]
Bayesian Information Criterion:	-17.64	8.41	1.52	-92.88
Marginal Effect Of Famine on: Adolescent Human Capital	.837	.837	.847	1.27
Years of Primary Schooling Lost Due To One Year Of Famine:	.87	.87	.88	1.19

Notes:

Standard errors in parentheses.
[a] Significant at the .01 level
[b] Significant at the .05 level
[c] Significant at the .10 level
[1]Famine is defined as an annual 33 percent drop in food production, based on the conservative lower end of crop failure percentage that informed the Indian Famine Codes (Howe and Devereux, 2004).

Table 3—continued

Mixed Coefficient Parameter Estimates Of Adolescent Human Capital Production Function: 1980 2010

Specification:	**(5)**	**(6)**	**(7)**	**(8)**
Regressand: Log of Average Years of Primary Schooling Completed by individuals age 15 19				
Regressors:				
Log of Food Production Index During Childhood: Age 0 5	.288	.285	.134	.212
	(.084)[a]	(.087)[a]	(.078)[c]	(.101)[b]
Log of Growth Rate of Population During Childhood: Age 0 5	-.122	-.099	-.074	-.121
	(.085)	(.085)	(.064)	(.088)
Log of Gross Capital Formation During Childhood: Age 0 5	.145	.144	.119	.154
	(.021)[a]	(.021)[a]	(.017)[a]	(.023)[a]
Constant	-1.45	-1.63	-.696	-1.33
	(.556)[b]	(.561)[a]	(.547)	(.705)[c]
Structure of Variance-Covariance:	Exchangeable	Identity	Identity	Identity
Structure of Residual Errors:	Independent	Exchangeable	Unstructured	Exponential
All Random Effects Significant?:	Yes	No	Yes	Yes
Diagnostics:				
Number of Observations	183	183	183	183
Likelihood Ratio Test vs. Linear Regression:	180.30[a]	188.40[a]	362.38[a]	274.65
Bayesian Information Criterion:	6.09	-7.22	-40.54	-93.47
Marginal Effect Of Famine on: Adolescent Human Capital	.845	.837	.354	.612
Years of Primary Schooling Lost Due To One Year Of Famine:	.89	.87	.42	.68

Notes:

Standard errors in parentheses.
[a] Significant at the .01 level
[b] Significant at the .05 level
[c] Significant at the .10 level
[1] Famine is defined as an annual 33 percent drop in food production, based on the conservative lower end of crop failure percentage that informed the Indian Famine Codes (Howe and Devereux, 2004).

Table 4
Mixed Coefficient Parameter Estimates Of Adolescent Human Capital Production Function Sub-Saharan Africa: 1980 2010

Specification:	**(1)**	**(2)**	**(3)**	**(4)**
Regressand: Log of Average Years of Primary Schooling Completed by individuals age 15 19				
Regressors:				
Log of Food Production Index During Birth (*in utero*)	.206 (.069)[b]	.206 (.056)[a]	.209 (.069)[a]	.211 (.070)[a]
Log of Growth Rate of Population During Birth (*in utero*)	.189 (.076)[b]	.189 (.074)[b]	.218 (.076)[b]	.179 (.077)[b]
Log of Gross Capital Formation During Birth (*in utero*)	.099 (.017)[a]	.099 (.012)[a]	.093 (.017)[b]	.101 (.017)[a]
Constant	-.998 (.429)[b]	-.998 (.370[b]	-.793 (.446)[c]	-1.10 (.429)[b]
Structure of Variance-Covariance:	Independent	Independent	Identity	Unstructured
Structure of Residual Errors:	Independent	Independent	Independent	Independent
All Random Effects Significant?:	No	No	Yes	No
Diagnostics:				
Number of Observations	182	182	182	182
Likelihood Ratio Test vs. Linear Regression:	216.32[a]	216.32[a]	197.68[a]	223.12[a]
Bayesian Information Criterion:	-3.80	22.22	25.23	-10.60
Marginal Effect Of Famine on: Adolescent Human Capital	.779	.779	.795	.799
Years of Primary Schooling Lost Due To One Year Of Famine During Birth (*in utero*):	1.05	1.05	1.07	1.07

Notes:

Standard errors in parentheses.
[a] Significant at the .01 level
[b] Significant at the .05 level
[c] Significant at the .10 level
[1] Famine is defined as an annual 33 percent drop in food production, based on the conservative lower end of crop failure percentage that informed the Indian Famine Codes (Howe and Devereux, 2004).

Table 4—continued
Mixed Coefficient Parameter Estimates Of Adolescent Human Capital Production Function
Sub-Saharan Africa: 1980 2010

Specification:	**(5)**	**(6)**	**(7)**	**(8)**
Regressand: Log of Average Years of Primary Schooling Completed by individuals age 15 19				
Regressors:				
Log of Food Production Index During Birth (*in utero*)	.209 (.069)[a]	.209 (.069)[a]	.241 (.058)[a]	.241 (.079)[a]
Log of Growth Rate of Population During Birth (*in utero*)	.216 (.075)[b]	.212 (.074)[b]	.158 (.030)[a]	.209 (.056)[a]
Log of Gross Capital Formation During Birth (*in utero*)	.093 (.017)[a]	.096 (.017)[a]	.007 (.013)	.078 (.019)[a]
Constant	-.805 (.446)[c]	-.870 (.442)[b]	.749 (.389)[c]	-.673 (.475)
Structure of Variance-Covariance:	Exchangeable	Identity	Identity	Identity
Structure of Residual Errors:	Independent	Exchangeable	Unstructured	Exponential
All Random Effects Significant?:	No	Yes	No	Yes
Diagnostics:				
Number of Observations	182	182	182	182
Likelihood Ratio Test vs. Linear Regression:	198.94[a]	204.10[a]	393.71[a]	279.06[a]
Bayesian Information Criterion:	13.57	24.02	-30.28	-50.93
Marginal Effect Of Famine on: Adolescent Human Capital	.795	.794	.789	.906
Years of Primary Schooling Lost Due To One Year Of Famine During Birth (*in utero*):	1.07	1.07	1.06	1.22

Notes:

Standard errors in parentheses.
[a] Significant at the .01 level
[b] Significant at the .05 level
[c] Significant at the .10 level
[1]Famine is defined as an annual 33 percent drop in food production, based on the conservative lower end of crop failure percentage that informed the Indian Famine Codes (Howe and Devereux, 2004).