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Why no adult stunting penalty or height premium? Estimates from native Amazonians in Bolivia

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ABSTRACT

Among adults of industrial nations, growth stunting (<-2 SD height Z score) is associated with worse indicators of adult well-being (e.g., income). Does adult stunting also inflict private costs in traditional societies? Adult stunting penalties or height premiums might only emerge when traditional societies modernize. Here we estimate the association between adult stunting and indicators of adult well-being using data from a panel study in progress among the Tsimane', a foraging–farming society of native Amazonians in Bolivia. Subjects included 248 women and 255 men $\geq$age 22 measured annually during 5 consecutive years (2002–2006). Nine outcomes (wealth, monetary income, illness, access to credit, mirth, schooling, math skills, plant knowledge, forest clearance) were regressed separately against a stunting dummy variable and a wide range of control variables. We found no significant association between any of the indicators of own well-being and adult stunting. Additional analysis showed that stunting bore an association only with poorer mid-arm muscle area. Height premiums and stunting penalties, though evident and marked in modern societies, might not be common in all traditional societies.

1. Introduction

A large body of evidence from low-income nations documents repeatedly the pervasiveness of childhood growth stunting—or being two standard deviations (SD) below the median height of a child's peers of the same age and sex in the USA (Engle et al., 2007; Grantham-McGregor et al., 2007; Walker et al., 2007). Childhood growth stunting (hereafter *stunting*) has received much attention in public health because it erodes cognitive abilities and health outcomes during childhood and adulthood (Fernand and Grantham-McGregor, 2002; Grantham-McGregor et al., 2000; Grantham-McGregor, 1995; Pollitt et al., 1995). In South Africa, a comparison of short-for-age "Cape Coloured" children showed that those growing up under poorer socioeconomic conditions had lower body weight, height, and physical performance than the more advantaged children (Henneberg et al., 1998). In adulthood,

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stunted children tend to end up as stunted adults (Liu et al., 2000; Coly et al., 2006). Among adults of industrial nations, standing physical stature is positively associated with many indicators of own adult well-being, such as occupation, monetary income, wages, IQ, longevity, and good health (Bogin and Keep, 1999; Case and Paxson, 2008; Komlos and Baur, 2004; Komlos, 1998; Pollitt et al., 1995; Waaler, 1984; Costa, 1993; Steckel and Rose, 2002).[1] At least among adults of industrial nations, growth stunting inflicts substantial private costs.

Is adult stunting negatively associated with various indicators of well-being in contemporary traditional rural societies? Research suggests that in pre-industrial, 17th and 18th century Europe, height disparities were great between the rich and the poor (Komlos et al., 1992; Komlos, 2007, 1994a,b). If height is associated with health and productivity, then it should be a marker of sexual attractiveness and reproductive success. Previous research on height premiums and stunting penalties has focused almost exclusively on reproductive outcomes and suggests that in *traditional* societies female height bears a positive association with reproductive success (Pollet and Nettle, 2008) but male height does not correlate well with own fertility or with child survival (Sear, 2006). Outside of reproductive success, the question of whether adult stunting negatively affects own adult well-being has barely been broached in traditional contemporary rural societies. A few studies explore the association between tallness and better socioeconomic outcomes in developing countries (Linnemayr et al., 2008; Dinda et al., 2006; Thomas and Strauss, 1997; Croppenstedt and Muller, 2000; Schultz, 2002, 2003a,b); however, none study this association in a traditional society.

One possible reason for the paucity of research on the consequences of adult stunting on own well-being in traditional societies has to do with the turbulent history of the "small-but-healthy" hypothesis. In the early 1980s Seckler (1982) advanced the hypothesis that in many areas of low-income nations, a short or stunted child (but not a wasted or a thin child) might be healthy and as productive as a non-stunted peer (Roos, 2009). He went on to argue that shortness might be an adaptation to mild to moderate malnutrition. The hypothesis generated much criticism (Beaton, 1989; Dasgupta, 1993; Martorell, 1989; Messer, 1986; Panter-Brick, 1998; Pelto and Pelto, 1989; Scheper-Hughes, 1992) in part because of the world-wide evidence that childhood stunting is associated with worse cognitive and health outcomes among children, but the small-but-healthy hypothesis leave unanswered our initial query of whether adult stunting abrades indicators of adult well-being such as income, wealth, human capital, and social capital in a traditional society.

Moreover, it is theoretically possible that in traditional societies adult stunting imposes no visible or obvious private socioeconomic costs on the stunted person, other than to erode immune function and work capacity. Even in industrial societies, the height premium applies to men (Nettle, 2002); for women there is a weight penalty and for both, a beauty premium (Hamermesh and Biddle, 1994; Cawley, 2004). In Denmark, BMI had an inverted U-shaped effect on wages for men (Greve, 2008). Here, we are cognizant of the cost of growth retardation to the immune function, but we focus our analysis on observable indicators of adult well-being, as listed below.

We estimate the association between a wide range of indicators of adult well-being (outcome variables) and stunting (main explanatory variable) in a native Amazonian society of foragers and farmers in the department of Beni, Bolivia (Tsimane') who are in the early stages of continual exposure to the market economy. Among indicators of well-being we selected economic outcomes (e.g., monetary income, wealth, area of forest cleared for agriculture), social outcomes (e.g., ability to borrow in an emergency), health outcomes (e.g., bed-ridden days), psychological outcomes (e.g., propensity to remain somber), and human-capital outcomes (e.g., schooling, math skills, practical ethnobotanical knowledge). We selected a wide range of indicators to ensure that the private costs of stunting or that the benefits of height are captured over many domains of high visibility. Adult stunting probably correlates with unobserved objective indicators of adult health (e.g., blood pressure, stress hormone levels), but we leave those health outcomes aside since we do not have current data on them. We define an adult as a person $\geq$22 years of age because Tsimane' stop growing by their early 1920s (Godoy et al., 2006a).

2. Materials and variables

2.1. Materials

We use a new 5-year annual panel (2002–2006, inclusive) that tracks about 1800 individuals of all ages in 13 villages (Leonard and Godoy, 2008a,b). The complete data and its documentation, along with publications from the Tsimane' Amazonian Panel Study (TAPS) project, are freely available for public use at the following address: http://people.brandeis.edu/~rgodoy/. During 1995–2001 we did background studies among the Tsimane' to identify villages for the panel study, to gain the trust of study participants, and to refine methods of data collection.

We selected the 13 villages to capture geographic variation in proximity to the market town of San Borja (mean = 25.96 km; SD = 16.70), the only town along the Maniqui River. To assess how representative the adult height data from the 13 villages is compared with the adult height of the rest of the Tsimane' population we draw on a larger data set of anthropometric measures of adults collected in 2000 in 59 Tsimane' villages (Foster et al., 2005). Adults in the 13 villages of the panel study were slightly taller than adults in the other villages. We computed height-for-age Z scores using the Frisancho (1990) norms for adults in the 13 villages of the panel study (n = 493) and for adults in the other 46 villages (n = 405). The adults in the 13 villages of the panel study

[1] Additional evidence of the height premium or the stigma associated with growth faltering comes from the increasing demand for growth hormones among young adults and their parents in industrial nations (Lagrou et al., 2008; Visser-van Balen et al., 2005; Waal and Verhulst, 1996).

had, on average, a height-for-age *Z* score of −1.76 (SD = 0.68), compared with the adults in the other villages, who had a height-for-age *Z* score of −1.98 (SD = 0.72) The mean standing height of adults were 149.82 cm (SD = 8.36) for women and 161.17 cm (SD = 12.09) for men A two-tailed *t*-test for the equality of the two means produced a *t*-statistic of 2.74 ($p = 0.006$).

The panel study in progress currently includes a total of 1995 people, but the sample used in this article includes only people over 22 years of age. The sample used contains a total of 493 people, with 248 females and 255 males. Of the 493 people, 64.5% were present during all five surveys. Seven percent were present during only one survey, 12.0% were present during only two surveys, 6.7% were present during only three surveys, and 10.6% were present during only four survey waves. We include a variable for the number of surveys in which we measured the person since temporary or permanent informative attrition might bias results (Gravlee et al., in press).

2.2. Outcome variables

The indicators of well-being fall under five categories:

2.2.1. Economic

(i) *Wealth*: the mean wealth was 1287.46 bolivianos (SD = 1329.07; minimum = 0; maximum = 14294; 1

Table 1
Definition of variables measured annually, 2002–2006 (inclusive), used in the regressions for Tsimane' ≥22 years of age.

Name of variable	Definition of variable
(A) Dependent variables (indicators of well-being)	
(I) Economic	
Income	Natural logarithm of monetary income earned during the 14 days before the day of the interview from the following sources: (1) the sale of forest goods, crops, domesticated animals, animal products (e.g., eggs), and (2) wage labor in logging camps, cattle ranches, and homestead of highland colonist farmers. +1 added.
Wealth	Natural logarithm of real monetary value of 22 physical assets owned by the person: (a) 5 traditional physical assets central to their subsistence (e.g., canoes, bows), (b) 13 modern physical assets that capture some luxury goods (e.g., radios) and modern technologies for agricultural production (e.g., cutlasses), and (c) 4 domesticated animals (e.g., chickens, ducks). +1 added.
Deforestation	Area deforested for agriculture by the entire household. Study participants reported areas in *tareas*, the local unit of area (1 ha = 10 *tareas*). Natural logarithm of area of forest cleared by household. +1 added. Only for male heads of household.
(II) Social	
Credit	Dichotomous variable for whether person reported having access to 100 bolivianos in an emergency (1 = access; 0 = no access)
(III) Health	
Bed-ridden days	Natural logarithm of total number of self-reported days in bed due to illness during the 14 days before the day of the interview. +1 added to raw values before taking logarithms
(IV) Psychological	
Somber	Did not laugh during the interview = 1; 0 = laughed
(V) Human capital	
Schooling	Maximum school grade completed. Ordinary least squares regression only for latest year, 2006.
Math ability	Score in math test to add, subtract, multiply, and divide. Ordinary least squares regression only for 2006. The answer to each of the four questions was coded as one (correct) or zero (incorrect). We added their score in each question to obtain a total math score (range: 0–4).
Ethnobotanical knowledge	Self-reported ability to make traditional objects from local wild and semi-domesticated plants. A sub-sample of participants ($n = 50$) was asked to list objects made from plants. From that list, we randomly selected 18 objects from 15 different plant species. We then asked people whether they had ever made the objects on their own. Scores were weighted to reflect the fact that only a few people reported knowing how to make difficult objects.
(A) Explanatory variables	
Stunting	Height was measured using protocol of Lohman et al. (1988) using stadiometer. Using age, sex, and height data, we computed age and sex-standardized height *Z* scores based on the norms of Frisancho (1990). From the *Z* score we created a dummy variable for stunting, which took the value of one if the person was below −2 SD, and zero otherwise.
Controls	
Age	Person's age in years
Sex	Male = 1; female = 0
Year	Year of survey
Survey participation	The number of surveys in which the person participated
Household size	Number of people in the household
BMI	Body-mass index (BMI = weight in kg/standing height in m^2)
Village dummies	A full set of 12 village dummy variables ($n = 13 - 1 = 12$), one for each village, included in the regression to control for village fixed effects

US$ ≈ 8 bolivianos during the study period). A two-tailed t-test for the equality of two means revealed that men have significantly more wealth than women ($p = 0.000$) (Table 1). We measured the inflation-adjusted (or *real*) monetary value of a person's wealth in 22 modern and traditional physical assets. We added the nominal monetary value of five traditional physical assets (canoes, bows), 13 modern physical assets (radios, cutlasses (or machetes)), and four domesticated animals (chickens, ducks). Based on ethnographic knowledge of the Tsimane', we selected a range of physical assets to capture wealth differences in the entire sample and between women and men. For instance, the poorest people own bows, arrows, and small animals (e.g., chickens), but better-off people are more likely to own large domesticated animals (e.g., cattle) and expensive industrial goods (e.g., guns). Among the assets measured, we included assets that women generally own (e.g., bags, pots, small animals), and assets that men generally own (e.g., cattle, guns). We multiplied the quantity of the asset by the selling price of the asset in the village to estimate the value of that asset, and added the value of the different assets to arrive at a monetary measure of total wealth for the person. Current nominal values for wealth were transformed into real values using the consumer price index for agricultural and natural resources of Bolivia.[2]

(ii) *Income*: we measured the monetary income earned during the 14 days before the day of the interview from the following sources: (1) the sale of forest goods, crops, domesticated animals, animal products (e.g., eggs), and (2) wage labor in logging camps, cattle ranches, and homestead of highland colonist farmers. The mean income was 111.30 bolivianos (SD = 261.55; minimum = 0; maximum = 8500). Based on a two-tailed t-test, men earned on average 131 bolivianos more than women ($p = 0.001$).

(iii) *Deforest*: we measured the area deforested for agriculture by the entire household. Study participants reported areas in *tareas*, the local unit of area (1 ha = 10 *tareas*). Area deforested provides a reasonable proxy for food consumption and monetary income since Tsimane' clear the forest mainly to grow crops for themselves and to plant rice as a cash crop (Godoy et al., 2009).

2.2.2. Health

We estimated self-reported morbidity by asking people to report all the days they had been bed-ridden from illness during the 14 days before the day of the interview. Results of a two-tailed t-test suggest that there was no significant difference between men and women in the average number of bed-ridden days (t-statistic = 0.98, $p = 0.32$).[3]

2.2.3. Social

We asked people about their self-reported ability to obtain 100 bolivianos in an emergency and coded the variable as one if the person reported being able to borrow this amount, and zero otherwise. We note, however, the possibility of social desirability bias and that respondents could overstate their ability to obtain credit. We use the variable as a proxy for social capital available to the person when an unexpected, adverse shock strikes. Men were more likely to have access to credit in an emergency compared with women ($\chi^2 = 44.46$; $p = 0.000$).

2.2.4. Psychological

During the interview surveyors noted whether the person smiled or remained somber. In the analysis the *somber* variable takes the value of one if the person neither smiled nor laughed, or only smiled during the interview, and it took the value of zero if the person laughed during the interview. Smiles have been shown to be reliable cross-cultural marker of mirth (Godoy et al., 2005b, in press-b). Individuals who smiled had better self-perceived health, more social capital, and higher body-mass index (BMI = weight in kg/standing height in m^2) than those who did not smile during interviews (Godoy et al., 2005b). Smiling is also an attribute of attractiveness, which was found to confer additional benefits such as higher earnings in studies conducted among people in the USA, Canada, and Argentina (Hamermesh and Biddle, 1994; Mobius and Rosenblat, 2006). Women were more somber than men ($\chi^2 = 6.61$; $p = 0.01$).

2.2.5. Human capital

(i) *Schooling* was measured by asking people about the maximum years of completed schooling. The mean years of schooling attained was 1.68 years (SD = 2.36; minimum = 0; maximum = 13). For 2006, a two-tailed t-test suggested that men had on average 0.56 more years of schooling than women (t-statistic = −1.01, $p = 0.31$).

(ii) *Math* scores were computed from a test in which people were asked to solve four problems; each question was designed to test the participant's ability to add, subtract, multiply, and divide. The answer to each of the four questions was coded as one (correct) or zero (incorrect). We added their score in each question to obtain a total math score (range: 0–4). Men scored 1.19 more points than women (t-statistic = −9.77, $p = 0.001$).

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[2] The deflators come from the Unidad de Análisis de Políticas Sociales y Económicas (UDAPE), a policy analysis bureau of the Bolivian government. The information was downloaded on March 3, 2008 from the following web address of UDAPE: http://www.udape.gov.bo/ (Table 1.1.5, Deflactores implícitos del PIB por rama de actividad económica). The deflators (base = 1990) were: 2002 = 222.23, 2003 = 231.50, 2004 = 257.70, 2005 = 235.14, and 2006 = 247.85.

[3] We use a window of 14 days because our early work with the Tsimane' (1995–2001) showed that longer periods of time were too long to recall. Since most Tsimane' self-medicate with local plants, using health records would provide an incomplete picture of their health. We exclude objective markers of health such as blood pressure because the stress here lies with how stunting correlates with visible indicators of well-being.

(iii) *Plant knowledge* was measured by asking subjects about their self-reported ability to make traditional objects from local wild and semi-domesticated plants. We first asked a sub-sample of participants ($n = 50$) to list objects made from plants. From that list, we randomly selected 18 objects from 15 different plant species. We then asked people whether they had ever made the objects on their own. We weighted scores to reflect the fact that only a few people reported knowing how to make difficult objects. The score for an object was inversely proportional to the number of participants who reported knowing how to make the object (Reyes-García et al., 2007). Men scored 0.49 more points than women in the test of plant knowledge (t-statistic = −2.73, $p = 0.006$).

2.3. Explanatory variable

2.3.1. Height Z score

We used the protocol of Lohman et al. (1988) to measure height. We recorded standing physical stature to the nearest millimeter using a portable stadiometer.[4] Using age, sex, and height data, we computed age and sex-standardized height Z scores based on the norms of Frisancho (1990). From the Z score we created a dummy variable for stunting, which took the value of one if the person was below −2 SD, and zero otherwise. Later, we do sensitivity analysis to make sure that our main results do not hinge on the definition of stunting. In additional analysis, we use the raw continuous variable of height as an explanatory variable instead of stunting.

2.4. Control variables

These included the person's age, sex, survey year, number of people in the household, the number of surveys in which the person participated, a full set of community dummy variables ($n = 13 - 1 = 12$), and BMI. We include BMI because of the association between adult stunting and BMI (Dasgupta, 1993; Frisancho, 2003, 2007; Popkin et al., 1996). Since height contributes to BMI, the parameter estimates of stunting may be affected by the collinearity with BMI. The correlation coefficient between height and BMI was 0.11 ($p = 0.001$). For this reason, we later re-estimate the basic regressions without BMI. The mean BMI for a Tsimane' adult over 22 years old was 23.57 (SD = 2.83; minimum = 10.8; maximum = 37.04). Income and BMI were significantly correlated with a small magnitude (correlation coefficient = 0.09, $p = 0.001$) (Fig. 1).

2.5. Analysis

We use panel linear regressions with individual random effects, clustering by person, and robust standard errors.

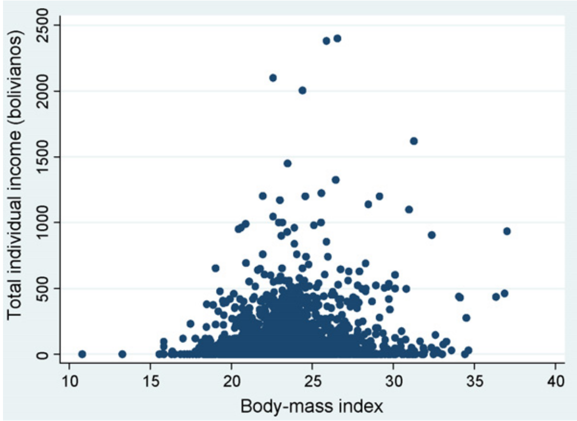

Fig. 1. The association between total individual income (bolivianos) and body-mass index for Tsimane' adults aged ≥22 years, 2002–2006.

For the statistical analysis we used Stata for Windows, version 10 (Stata Corporation, College Station, Texas).

3. The Tsimane': setting and findings from research in progress

3.1. Setting

The Tsimane' are a native Amazonian society of farmers and foragers in the department of Beni, Bolivia. They number about 8000 people and have been in sporadic exposure to Westerners since about the early 1950s (Huanca, 2008). Like many native Amazonian societies, Tsimane' practice hunting, plant collection, and slash-and-burn agriculture, with agriculture and cash cropping of rice becoming the dominant economic activities of households (Vadez et al., 2004). Tsimane' live in small villages of about 20 households (~6 people/household) and, like other native Amazonian societies, practice preferential cross-cousin marriage. The last five decades have seen the spread of modern health care facilities and a secular decline in adult mortality (Gurven et al., 2007), but no secular change in adult physical stature (Godoy et al., 2006a) or in infant and child mortality (Gurven et al., 2007).

The mean standing physical stature of adults were 149.82 cm (SD = 8.36) for women and 161.17 cm (SD = 12.09) for men (Fig. 2). During 1920–1980, the height declined by 0.01 cm/decade (women; $p = 0.44$) and 0.006 cm/decade (men; $p = 0.66$) (Godoy et al., 2006a). Both Tsimane' women and men were −1.8 SD below the median of their same sex and age peers in the USA (Frisancho, 1990). Of the 493 adult participants, 41.0% were stunted (females = 51.5%; males = 40.4%; $p = 0.80$).

During 2002–2006, Tsimane' experienced an annual growth in BMI of 0.71%/year after controlling for the following variables: age, schooling, household size, total wealth, self-reported morbidity, and annual rainfall. During the last year of the panel data (2006), men and non-pregnant women in the sample had an average BMI of 23.56 and 23.69. Given these BMI values, higher levels of BMI indicated better short-run nutritional status. BMI and income were positively associated with a small

[4] We are cognizant of the literature showing that short-for-age children growing up under different socioeconomic conditions develop different growth rates for specific body parts (Henneberg et al., 1998); unfortunately we did not have measures of sitting height, so we only used standing physical stature to calculate adult stunting.

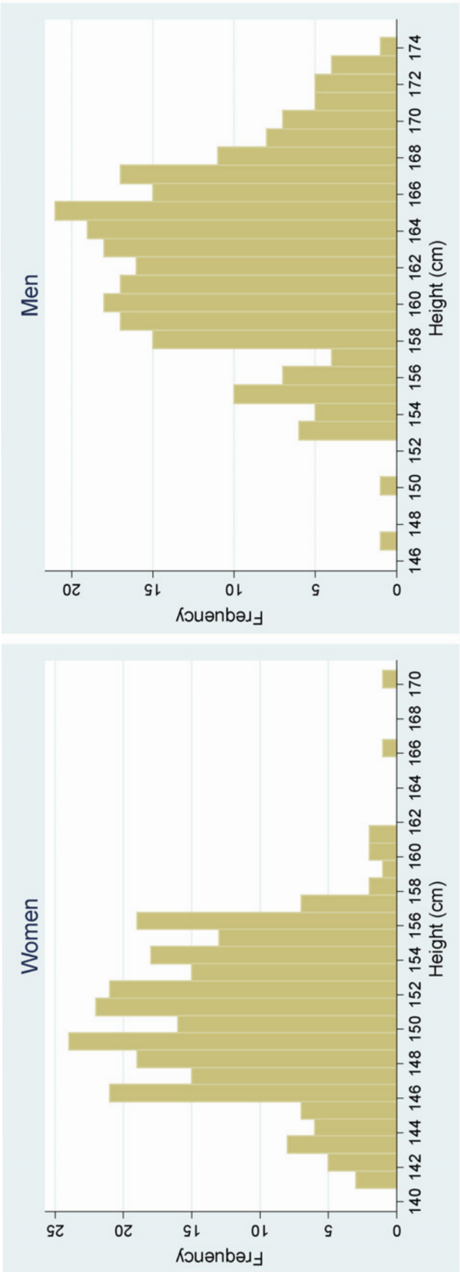

Fig. 2. Height distribution of Tsimane' adults aged ≥22 years by individual's sex, 2002–2006. *Note:* We excluded men measuring <146 cm and women measuring <140 cm in height due to the small sample of observations (n = 17) because these are likely coding errors.

magnitude (correlation coefficient = 0.10, p = 0.000) (Fig. 3).

On the negative side, the years 2002–2006 show an increase in the self-reported number of ailments during the two weeks before the day of the interview (+7.35/year) (Godoy et al., in press-a). Greater self-reported morbidity over time could reflect changes in the threshold of what it means to be healthy, but it could also mean worse objective health. We cannot separate these different interpretations, but note that research elsewhere in Amazonia suggests that native Amazonians may be suffering from a secular decline in health. Coimbra et al. (2001) found increasing prevalence of hypertension among the Xavante native Amazonians. The Matsigenka of the Peruvian Amazon also reported deteriorating self-perceived physical and mental health and productivity (Izquierdo, 2005).

3.2. Findings from research in progress

The most important findings from our published research among the Tsimane' that bear directly on this article include: (a) high rate of childhood growth stunting, with 44.9% of children ages 2–10 years growth stunted (Foster et al., 2005; McDade et al., 2007), owing in part to the pervasiveness of parasitic infections and immune activation (McDade et al., 2005; Tanner, 2005) and due also to a diet adequate in calories but lacking in key micronutrients (Godoy et al., 2005c), (b) no strong evidence of disparities in anthropometric indicators of short- or long-run nutritional status, perceived health, or modern human capital between girls and boys 2–13 yeas of age (Godoy et al., 2006b), (c) high levels of local knowledge of plants (Reyes-García et al., 2003, 2005), (d) positive associations between local knowledge of plants and child and adult health and conservation of natural resources (McDade et al., 2007; Reyes-García et al., 2007, 2008), (e) high levels of economic self-sufficiency (Godoy et al., 2007a,b,c) yet some variation in market exposure, (f) weather perturbations during gestation and early childhood left an imprint on the height of children and adults (Godoy et al., 2008b,c), and (g) Tsimane' have low levels of formal schooling, typically about 1–2 years of completed school.

4. Main results

4.1. Bivariate analysis

The results of a two-tailed t-test for the equality of two means and a chi-squared test suggest that, overall, there was no statistically significant difference between stunted and non-stunted Tsimane' adults on various indicators of well-being, with the exception of math ability, which was significant at the 5% level (p = 0.03) and wealth, which was significant at the 6% level (p = 0.054).

Stunted and non-stunted Tsimane' had about the same income (103 bolivianos, p = 0.84, Fig. 4), bed-ridden days (1.50 days, p = 0.67, Table 2), years of schooling (1.80 years, p = 0.09, Table 2), and scores in test of plant knowledge (4.30, p = 0.65, Fig. 5) (Table 2). In Table 2 and Fig. 6,

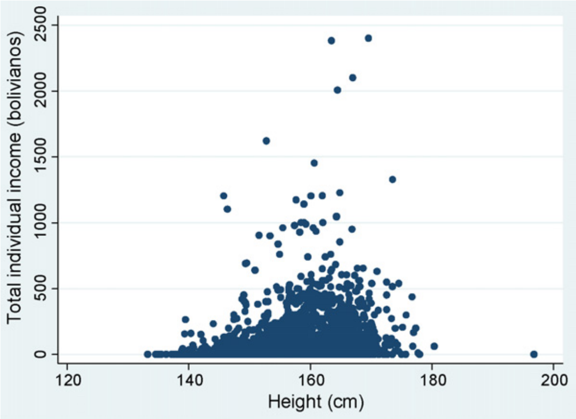

Fig. 3. The association between total individual income (bolivianos) and height (cm) for Tsimane' adults aged ≥22 years, 2002–2006.

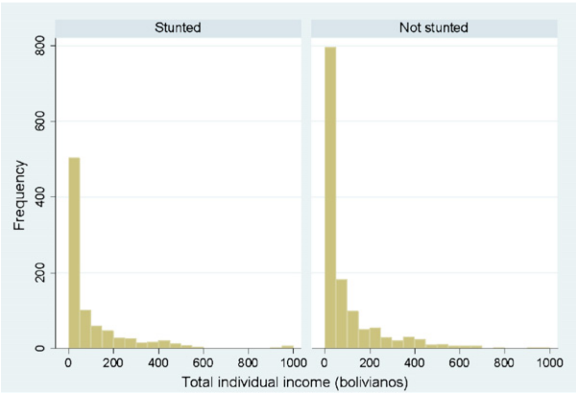

Fig. 4. Individual income distribution of Tsimane' adults aged ≥22 years by stunting status, 2002–2006. *Note*: We excluded stunted individuals earning >1000 bolivianos due to the small sample of observations ($n = 18$) where 18 = # outliers excluded.

Table 2
Dependent variables that proxy for well-being of Tsimane' adults aged ≥22 years by stunting status.

Measures of well-being	Stunting Mean values Yes	No	*p*-Value
Continuous variables			
Wealth	1381.82	1267.23	0.05
Income	104.30	102.03	0.84
Deforestation	4.67	4.33	0.23
Bed-ridden days	1.26	1.30	0.67
Body-mass Index	23.63	23.63	0.94
Schooling	2.00	1.62	0.09
Math ability	1.10	0.80	0.03
Plant knowledge	4.42	4.32	0.65

Measures of well-being	Percentages Yes	No	*p*-Value (Pearson's χ^2)
Categorical variables			
Psychology (somber; percent read down)			
Yes	44.19	46.57	$\chi^2 = 0.17$
No	55.81	53.43	$p = 0.27$
Social (ability to obtain credit in emergency; percent read down)			
Yes	41.14	42.10	$\chi^2 = 0.19$
No	58.86	57.90	$p = 0.65$

Results of two-sided *t*-test and Pearson's χ^2 test, 2002–2006.

stunted and non-stunted adults have roughly similar levels of wealth (~1300 bolivianos, $p = 0.054$) and math scores (~1 point, $p = 0.03$, Table 2), though the small differences in favor of stunted adults are statistically significant. In Table 2, the chi-squared test suggests that stunted and non-stunted Tsimane' did not differ in mirth ($\chi^2 = 1.17$; $p = 0.27$) and ability to obtain credit in an emergency ($\chi^2 = 0.19$; $p = 0.65$).

4.2. Multivariate analysis

The most striking result of regression is the absence of any association between adult stunting and any of the nine indicators of adult well-being (Table 3). In fact, adult stunting bore an unexpected sign in most of the regressions. Adult stunting was associated with *higher* levels of wealth (column [1]; coefficient = 0.01, $p = 0.532$), monetary income (column [2]; coefficient = 0.06, $p = 0.196$), deforestation (column [3]; coefficient = 0.01, $p = 0.721$), school achievement (column [7]; coefficient = 0.19, $p = 0.369$),

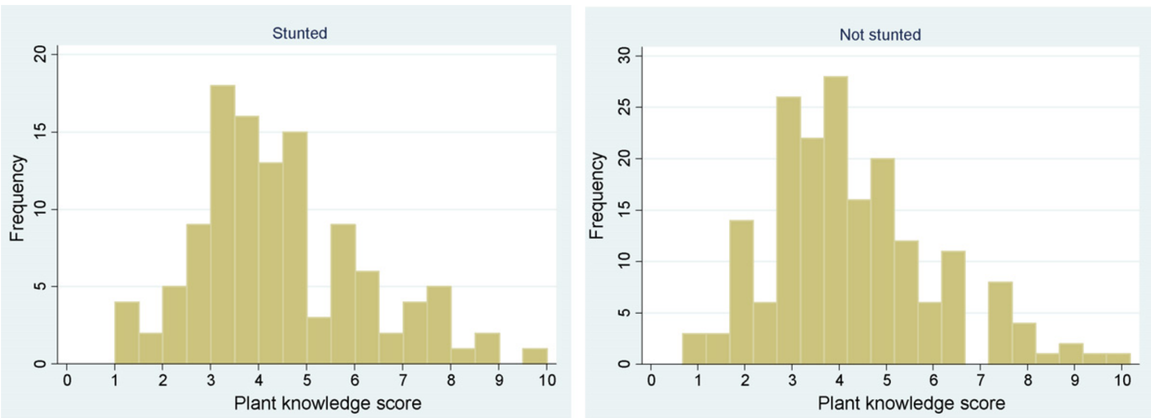

Fig. 5. Distribution of score on test of plant knowledge (range 0–10) of Tsimane' adults aged ≥22 years by stunting status, 2002–2006.

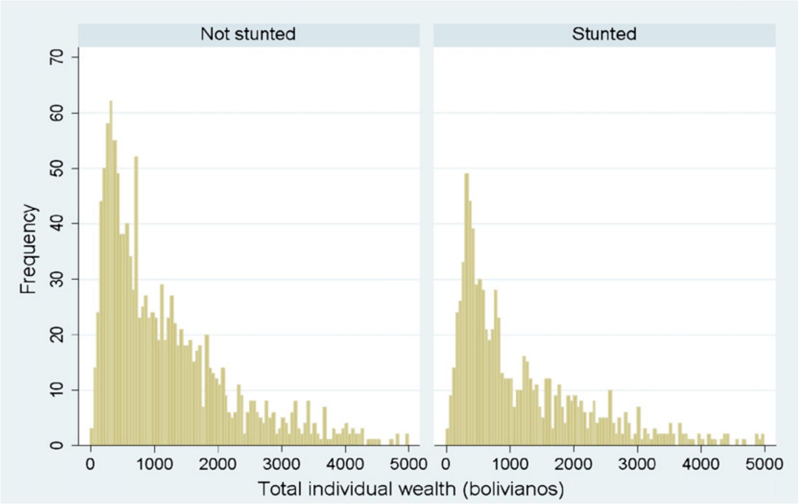

Fig. 6. Individual wealth distribution of Tsimane' adults aged ≥22 years by stunting status, 2002–2006. *Note*: We used the cut-off point of 5000 bolivianos per person due to the small sample of observations (n = 48) where 48 = # outliers excluded for individuals with wealth valued at over 5000 bolivianos.

math scores (column [8]; coefficient = 0.20, p = 0.108), and with a *lower* propensity to be somber during the interview (column [6]; coefficient = −0.01, p = 0.576). Only with the perceived ability to obtain credit in an emergency (column [5]; coefficient = −0.006, p = 0.732) and with the test of practical ethnobotanical knowledge (column [9]; coefficient = −0.01, p = 0.932) did stunting produce results in the direction one might have expected. However, in none of the nine regressions were results statistically significant at the conventional 95% confidence interval or higher.

5. Robustness analysis of main results

To explore how the height premium might vary by sex (Nettle, 2002; Pollet and Nettle, 2008; Sear, 2006, we generated an interaction variable, stunted*male, and included it as an additional regressor in each equation. In none of the new regressions was the interaction term statistically significant at the 95% confidence interval. To control for individual fixed heterogeneity we re-estimated regressions [1,2] and [4,6] using an individual fixed-effect panel linear model and obtained much smaller coefficients and even weaker statistical results.[5] We also included a quadratic term for age but found no significant association between stunting and outcome variables. We re-estimated the regressions without BMI to remove possible collinearity with stunting, and found essentially the same results as those shown in Table 3.

In Section 1 we noted that the height premium or the stunting penalty may only emerge in more stratified societies and modern, formal economies. To explore the idea we re-estimated the regressions of Table 3 with an additional interaction term, near*stunting. The variable 'near' took the value of one if the village was in the lowest 25% of the village-to-town distance measures and zero if the village was in the top 25% (i.e., farther away). While four of the nine variables were significant, three of them had a sign that ran counter to the hypothesized relation. Stunted adults who lived closer to towns had 9.55% (p = 0.009) more wealth and 26.67% (p = 0.013) more income, and were 13.95% (p = 0.002) more likely to have access to credit in an emergency compared with their peers in more isolated communities. However, stunted adults living nearer to towns reported having spent 17.10% (p = 0.028) more days in bed due to illness than their peers farther away from town.

Two regressions of Table 3 had a dichotomous variable as an outcome. We re-estimated the regressions for the ability to obtain credit in an emergency and the propensity to be somber using Probit regressions with robust standard errors and found that the signs remained the same and that the results were still non-significant for being somber (coefficient = −0.181, p = 0.23) and for obtaining credit (coefficient = −0.025, p = 0.84).

6. Additional analysis

While we do not have data on reproductive success, we have data on arm muscle area. Spurr (1983) noted that stunted adults might have reduced muscle mass. To explore the idea we used the age and sex-standardized Z score of arm muscle area using the norms of Frisancho (1990) as an outcome and all the covariates of Table 3. Using an individual random-effect panel linear regression, we found that stunting was associated with 0.17 *lower* standard deviations (p = 0.0001) in arm muscle area, with a much stronger negative association among men (−0.22 SD, p = 0.0001) than among women (−0.13 SD, p = 0.01). When we use the continuous mid-arm muscle area variable, stunting was associated with a 0.49 cm lower arm muscle (p = 0.000) for both men and women, with 0.73 cm (p = 0.000) lower arm muscle for men and 0.29 cm

[5] We did not run a fixed-effect individual regression for deforestation because deforestation was measured at the level of the household, and human-capital variables (columns [7–9]) did not vary between years.

Table 3
Association between indicators of adult well-being (outcome variables) against adult stunting among Tsimane' over 22 years of age: Results of individual random-effect multiple linear regressions with robust standard errors and clustering by individual, 2002–2006 (stunted = $\leq$2 SD in height-for-age *Z* score).

Explanatory variables	Indicator of well-being (outcome variable)								
	Economic			Health	Social	Psychological	Human capital		
	Wealth [1]	Income [2]	Deforest [3]	Illness [4]	Credit [5]	Somber [6]	School [7]	Math [8]	Plants [9]
Stunted	0.01	0.06	0.01	−0.02	−0.01	−0.006	0.19	0.20	−0.016
Male	0.42**	0.82**	NA	−0.11**	−0.05*	0.13**	1.49**	1.18**	0.60**
Age	0.006**	−0.003*	0.008**	0.003**	−0.0003	−0.0006	−0.05**	−0.03**	0.04**
BMI	0.01**	0.009	0.01	−0.01	−0.009*	0.005	0.10	0.03*	0.02
House size	0.005	0.002	0.07**	0.01*	−0.002	0.003	−0.08**	−0.07**	0.01
N	2188	2199	979	2210	2171	2193	457	449	299
R squared overall	0.38	0.23	0.18	0.05	0.05	0.05	0.21	0.34	0.33

Notes: Cells contain coefficients. Regressions contain robust standard errors, constant, number of surveys in which person participated, and full set of village dummy variables ($n = 13 - 1 = 12$), none shown. Log, natural logarithm. NA, not applicable. Dependent variables:
[1] Wealth = natural log of real monetary value of 22 physical assets owned by the person: (a) 5 traditional physical assets central to their subsistence (e.g., canoes, bows), (b) 13 modern physical assets that capture some luxury goods (e.g., radios) and modern technologies for agricultural production (e.g., cutlasses), and (c) 4 domesticated animals (e.g., chickens, ducks). +1 added.
[2] Income = natural logarithm of monetary income earned from sale of goods and from wage labor. +1 added.
[3] Deforest = natural logarithm of area of forest cleared by household. +1 added. Only for male head of household.
[4] Illness = natural logarithm of total number of bed-ridden days due to illness during the 14 days before the day of the interview.
[5] Credit = dichotomous variable. 1 = person reported having access to 100 *bolivianos* in an emergency, and zero otherwise.
[6] Somber = dichotomous variable. 1 = person was somber in interview; 0 = person smiled or laughed many times in interview.
[7] School = maximum school grade completed. Ordinary least squares regression only for latest year, 2006.
[8] Math = score in math test to add, subtract, multiply, and divide (range: 0–4). Ordinary least squares regression only for 2006.
[9] Plants = score in test of practical ethnobotanical knowledge.
Explanatory variables: [a] Stunted = 1 if person $\leq$2 SD in height *Z* score, 0 otherwise; [b] male = 1 if person is male, and zero otherwise; [c] age of person in years; [d] BMI = kg/m^2; [e] household size = number of people in household at time of survey.
* Significant at the $\leq$5% level.
** Significant at the $\leq$1% level.

($p = 0.024$) for women. These findings suggest that a further somatic cost of adult stunting could result in reduced adult muscularity, with men incurring the strongest reductions.

Another possible criticism relates to the definition of stunting. Defining stunting as being below two standard deviations in height relative is arbitrary and varies upon the standard reference used (Brunson et al., 2008). Defining stunting as <-2 SD in *Z* score for height may reduce our ability to capture variation in a sample population in which nearly half of the individuals meet the criteria for stunted. Under this scenario, people right above and below our cut-off point for stunted may be very similar in actual height. Instead, it might be more illuminating to re-estimate the regressions of Table 3 with (a) the raw measure of height as a covariate, (b) a dummy variable for severely stunted, or people below −3 SD in height, or (c) with a locally based norm of stunting.

We first discuss point (a). For brevity, we show only the new coefficients for the height variable (cm) for each of the nine outcomes of Table 3. The new regressions were identical to the regressions of Table 3, except that we dropped the variable for stunting and we put instead the continuous variable of height. The new coefficients for height were as follow: [1] wealth = −0.002 ($p = 0.181$), [2] income = −0.002 ($p = 0.541$), [3] deforest = 0.0003 ($p = 0.956$), [4] illness = 0.004 ($p = 0.235$), [5] credit = 0.003 ($p = 0.075$), [6] somber = −0.001 ($p = 0.604$), [7] schooling = 0.013 ($p = 0.391$), [8] math = 0.0009 ($p = 0.920$), and [9] ethnobotanical skills = 0.003 ($p = 0.844$). As before, none of the results were statistically significant at the 95% confidence interval.

To address point (b), we re-estimated the regressions of Table 3 without the dummy variable for stunted; instead we included the dummy variable for severely stunted. We found no significant association between the new variable for stunting and any of the nine outcomes. To address point (c), we normalized the height variable for each sex and defined stunting as being below 2 SD using the local norm. Again, we found no significant result at the 95% confidence interval.

7. Discussion and conclusions

Why might adult stunting bear no association with indicators of adult well-being, and what are the implications of the finding for the "small-but-healthy" hypothesis?

One reason for the weak results might have to do with standard methodological shortcomings, including measurement errors (Godoy et al., 2008a). The first type of error will generate an attenuation bias and the second type of error will inflate standard errors. Together, they will enhance the likelihood of accepting the null hypothesis of no effect. Though theoretically possible, we doubt this is a major reason for the weak results because other variables for which we have much more accurate measures (e.g., deforestation) (Vadez et al., 2003) or for which we have objective measures (e.g., math skills) also produced weak and counter-intuitive results. Another methodological reason for the weak results might have to do with biases from omitted variables. As noted, stunting is typically ascribed to attributes of the person and of the mother, and to the socioeconomic and demographic environment. Our use of individual fixed effects controls for the role of individual attributes that remained fixed during the study period, but it does not allow us to control for attributes of the person that changed during 2002–2006 but that we did not measure.

A second, more substantive, reason for the weak associations between adult stunting and adult indicators of well-being has to do with the presumably adverse consequences of stunting in foraging–farming societies in the early stages of integration to the market economy. In industrial societies, height (a proxy for long-term nutritional status and health) bears a positive association with canonical indicators of adult well-being in part because it is associated with greater human-capital accumulation, particularly schooling (Case and Paxson, 2008). Of course, there are many other reasons for the association between height and human capital accumulation such as intergenerational transmission of social status, education, and income. In a traditional rural society without much schooling or with modest pay-offs to academic skills (Foster and Rosenzweig, 1996), the main mechanisms by which height enhances well-being in industrial societies might be absent, and so height might have no pathway through which to influence socioeconomic indicators of well-being. The other main form of human capital in these societies – local knowledge of the environment, of plants, wild animals, soils, climate, and the like – is learned from trial and error, direct observation, and from one's peers and elders, and is widely shared (Reyes-García et al., 2003, in press). In industrial societies individuals accumulate human capital credential and academic skills for themselves or through parents, family, friends, social network; these stocks of knowledge for the most part are not shared. Moreover, in a market economy, one's health (or height) might matter much in the formal labor market. But in a traditional rural, highly endogamous, economically self-sufficient society where all people are linked by kinship bonds of blood and marriage, it is possible that one's individual health might not matter much in the accumulation of human capital since this type of human capital is shared.

Another possible reason for the ubiquity of stunting in rural areas of low-income nations may have to do with modest height premiums and stunting penalties among adults as *perceived* by parents. Orthodox explanations of childhood stunting focus on the *past* or on the *current* environment, including (1) child attributes (Fernald and Neufeld, 2007; Kalanda et al., 2005; Simondon et al., 1998), (2) maternal attributes (e.g., conditions *in utero* and before pregnancy) (Adair, 1999; Gray et al., 2008; Kuzawa, 2008), and (3) household and community socioeconomic and demographic attributes during pregnancy and during the period of child growth (Carba et al., 2009; Barker, 2006; Eckhardt et al., 2005; Kain et al., 2005; Leonard et al., 2000; Martorell and Scrimshaw, 1995). Studies have shown that there is cross-cultural variability in how parents view child growth and appropriate size, and whether stunting might be a problem worth correcting (Reifsnider et al., 2000; Jahn and Aslam, 1995; Lucas et al., 2007); in some cases, parents may perceive stunting as hereditary and therefore beyond their control (Reifsnider et al., 2000). So far, researchers have not incorporated the role of parental expectations about the future benefits of adult tallness or the future costs of adult stunting in models of child growth. In some societies, as a result of their lower productivity compared with adults, children receive less health care (Sauerborn et al., 1996) and food allocation (Wheeler, 1991; Pitt et al., 1990).

Moreover, adult height might not confer benefits in traditional rural societies if other, more reliable indicators of desirable characteristics are defined by the sociocultural context.

What are the implications of our findings for the "small-but-healthy" hypothesis? Using musculature as an outcome, we found the expected negative association between shortness and this one dimension of health. So this part of our analysis would lead us to reject the "small-but-healthy" hypothesis, at least for this indicator of objective health.

Further investigation should explore the longitudinal dimension of growth patterns to evaluate whether the height premium increases as individuals and communities engage more intensively in market activities. As Tsimane' engage in these market activities and experience changes in the social fabric that bind the network of shared human capital, height, particularly for men, may emerge as a symbol of status and of economic prestige in this population.

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