Supplemental material

Climate Change, Crop Yields, and Undernutrition: Development of a Model to Quantify the Impact of Climate Scenarios on Child Undernutrition

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Contents

Annex 1. Calculation of the development score

The formula for calculating the development score is:

$$w_{ij} = \begin{cases} -\frac{(a_{ij} - a_{max})}{(a_{max} - a_{min})} & if\ a_{ij} \leq \tau \\ 0 & if\ a_{ij} > \tau \end{cases} \quad \forall i,j \qquad [S1]$$

where:

$$a_{ij} = \ln\left(\frac{\text{GDP/capita}_{ij}}{\text{Gini}_{ij}}\right) \qquad [S2]$$

a_{max} = maximum value of a_{ij} across all countries i with $a_{ij} \leq \tau$ in all regions j,
$a_{max} = \max_{i,j}\{a_{ij}\}$

a_{min} = minimum value of a_{ij} across all countries i with $\frac{GDP}{capita_{ij}} \leq \tau$ in all regions j,
$a_{min} = \min_{i,j}\{a_{ij}\}$

$\tau = 10$, the cut-off value for a based on a GDP/capita of \$10 000 (USD 2000 US) and a Gini coefficient of 0.38

GDP/capita_{ij} = Gross Domestic Product per capita for country i in region j
Gini_{ij} = Gini coefficient (World Bank 2011) of country i in region j.

(Note the operators $max_{i,j}\{.\}$ and $min_{i,j}\{.\}$ respectively mean the maximum or minimum of the argument in $\{.\}$; $\forall$ means 'for every')

Analysis of data for the present for GDP/capita, stunting and undernourishment, suggests that when GDP/capita is above \$10 000 (US 2000) that both undernourishment and stunting are rare. This GDP/capita is approximately the lower end of the range seen in Western Europe, and socioeconomic conditions in Western Europe can generally be considered to be adequate in terms of avoiding stunting. We use an associated Gini coefficient of 0.38 to define minimum distribution of wealth necessary (In 1997 in Portugal, GDP/capita was \$10,200 and Gini was 0.385). Based on these observations, we assume that once wealth reaches the equivalent of a GDP/capita of \$10 000 (USD 2000) with a Gini of 0.38, that non-food causes of stunting are absent; that is, at and above this level, the development score is set to 0.

The initial scaling of the development score was done using a dataset for all countries (i.e. all countries across the globe) for which current GDP/capita and Gini coefficient data were available. This means, in the scaling from 0 to 1, 1 represents the 'worst' conditions currently observed, and 0 represents the 'best' conditions (capped as described above).

We note that this means that if conditions worsen in countries with very poor conditions currently, there is little room for the scaled development score to represent this (as the score will already be close to 1). In practice, however, the scenario we examined (as is common to all currently available socioeconomic scenarios for the future) assumes there is growth in GDP/capita in all countries; that is, there is no need to scale the score to allow the worst off countries to worsen. If the need arises to allow for worsening conditions, the development score could be re-scaled appropriately.

Annex 2. Estimating proportion undernourished (PoU)

Our model required projections of future proportion undernourished (PoU) with and without climate change. Nelson et al (2009) estimated country-level average per capita calorie availability in 2050 using five crop models (wheat, rice, maize, soy and groundnut) and the IMPACT trade model. For details of the assumptions in the crop modelling (e.g. regarding CO_2 fertilization, irrigation and adaptation responses, etc), extrapolations to other food groups, and the trade model see Nelson et al (2009).

We used the estimates of country-level per capita calorie availability to estimate PoU using the FAO method (FAO 2003). The FAO method assumes that the within-population distribution of calories is described by a log-normal distribution, and is driven by estimates of (i) the coefficient of variation for within-population calorie distribution, (ii) the average minimum calorie requirement to avoid undernourishment in the population, and (iii) per capita calorie availability (see FAO (2003) for details). As scenario (future) data were not available for either (i) or (ii), we obtained current estimates (FAO 2010) and assumed they remained constant at current (baseline) levels.

Supplemental Material, Table 1. Percentage of Monte Carlo simulation estimates rejected for having values < 0 without and with future climate change[a]. All numbers are percentages.

	No climate change		With climate change	
Region	**Severe stunting**	**Moderate stunting**	**Severe stunting**	**Moderate stunting**
South Asia	27	0	8	0
Sub-Saharan Africa, Central	<5	0	<5	0
Sub-Saharan Africa, East	14	0	<5	0
Sub-Saharan Africa, South	18	0	<5	0
Sub-Saharan Africa, West	<5	0	<5	0

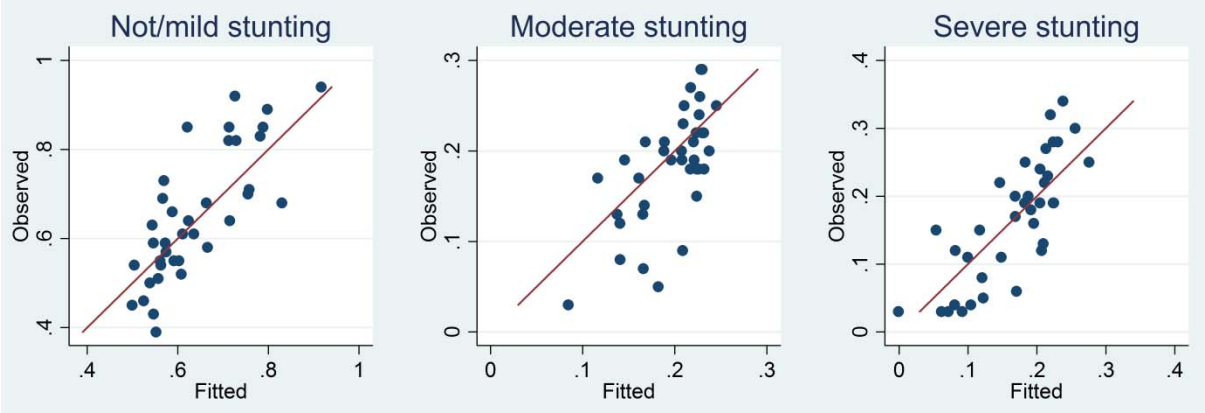
[a] In the Monte Carlo simulation, it was possible to obtain estimates where proportion stunted was <0 or >1. Thus we ran the simulation 500 000 times and selected the first 100 000 estimates that were >0 and <1 which potentially introduced bias. There were no estimates >1, meaning there was no risk of downward bias. This table shows the percentage of estimates that were rejected for being <0, which potentially introduces upward bias. More estimates for severe stunting were rejected in the 'no climate change' compared to the 'climate change' future which may have reduced the apparent impact of climate change on severe stunting.

Supplemental Material, Table 2. Countries in each region[a]. Countries marked with an asterisk* did not have complete data and were excluded from the simulation.

South Asia	**Sub-Saharan Africa, East**	**Sub-Saharan Africa, West**
Afghanistan*	Burundi	Benin
Bangladesh	Comoros*	Burkina Faso
Bhutan	Djibouti	Cameroon
India	Eritrea*	Cape Verde*
Nepal	Ethiopia	Chad
Pakistan	Kenya	Cote d'I'voire
	Madagascar	Gambia
Sub-Saharan Africa, Central	Malawi	Ghana
Angola	Mayotte*	Guinea
Central African Republic	Mozambique	Guinea-Bissau
Congo	Rwanda	Liberia
Democratic Republic of the Congo	Somalia*	Mali
Equatorial Guinea*	Sudan*	Mauritania
Gabon	Uganda	Niger
	United Republic of Tanzania	Nigeria
Sub-Saharan Africa, South	Zambia	Saint Helena*
Botswana		Sao Tome & Principle*
Lesotho		Senegal
Namibia*		
South Africa*		
Swaziland		
Zimbabwe		

[a] We used regions previously defined for the Global Burden of Disease Study 2010 (Institute for Health Metrics Evaluation 2010)

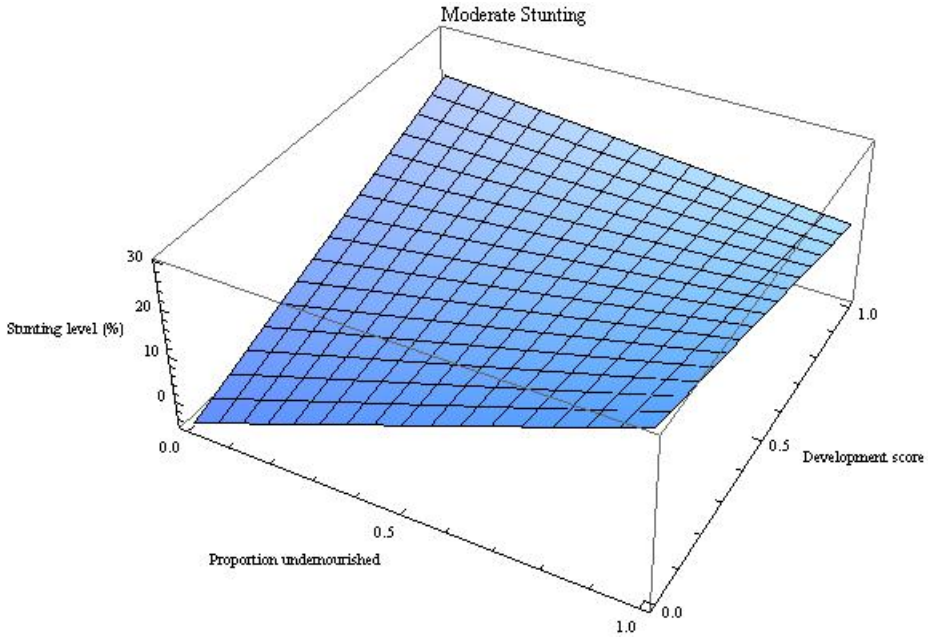
Supplemental Material, Figure 1. Model validation: scatter plots showing observed versus fitted estimates[a].



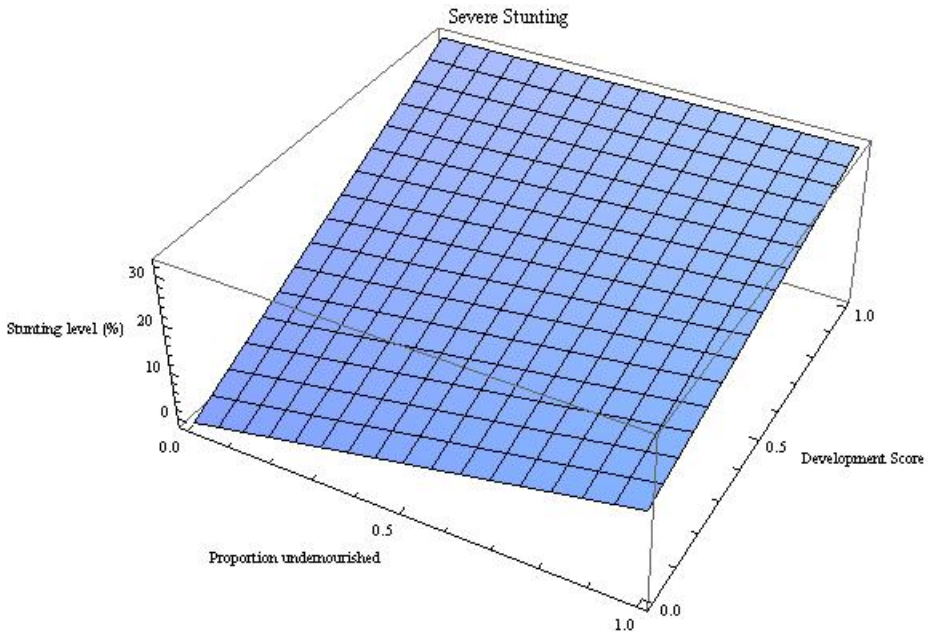
[a] The model was validated using the validation dataset (37 records). The x-axis is the model estimate, the y-axis is observed stunting, and the line shows a perfect fit.

Supplemental Material, Figure 2. Equation surface plots for A) moderate stunting and B) severe stunting

A) Moderate stunting



B) Severe stunting



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