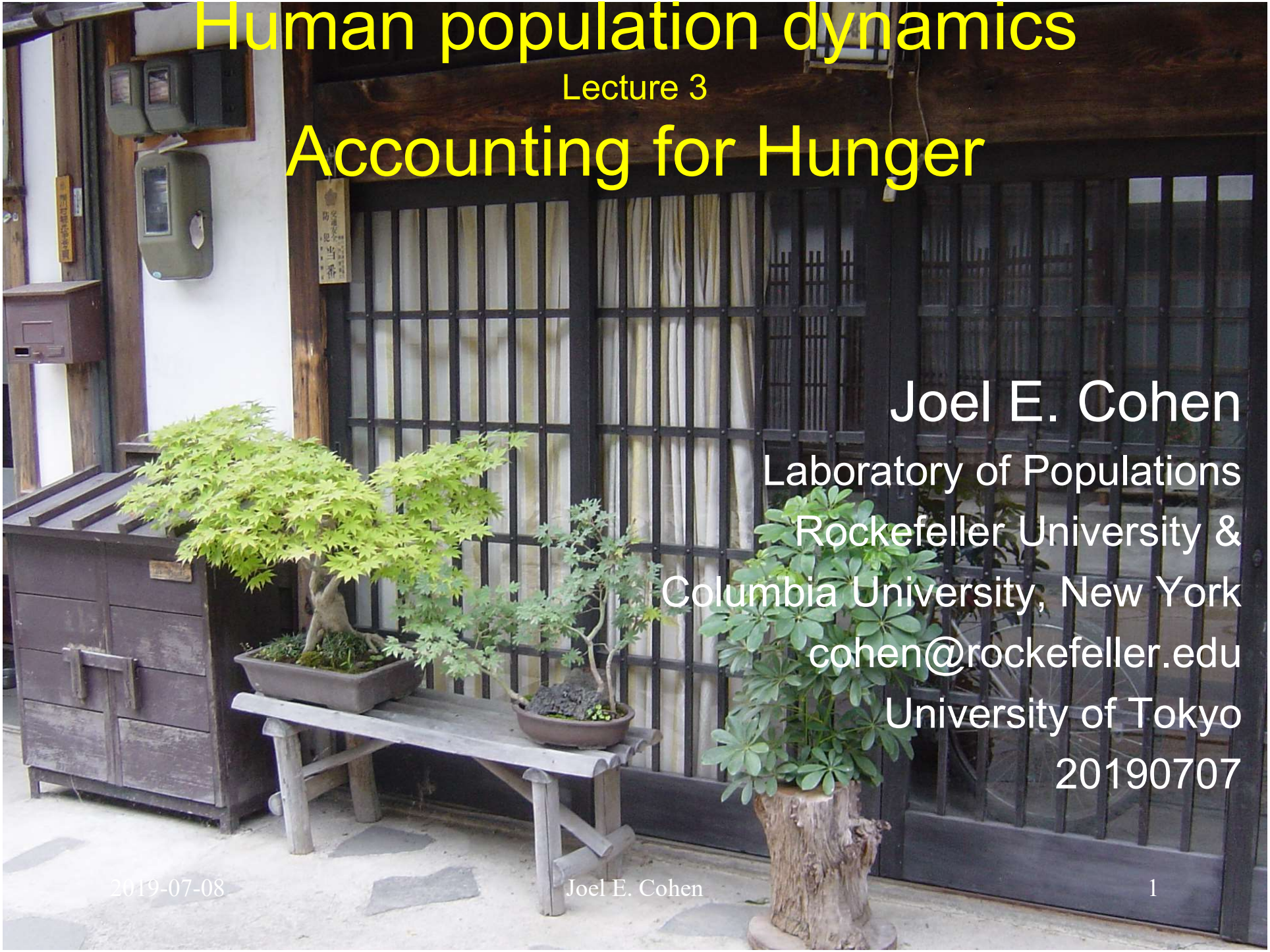
Human population dynamics

Lecture 3

Accounting for Hunger



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Outline

➔ Superabundant food

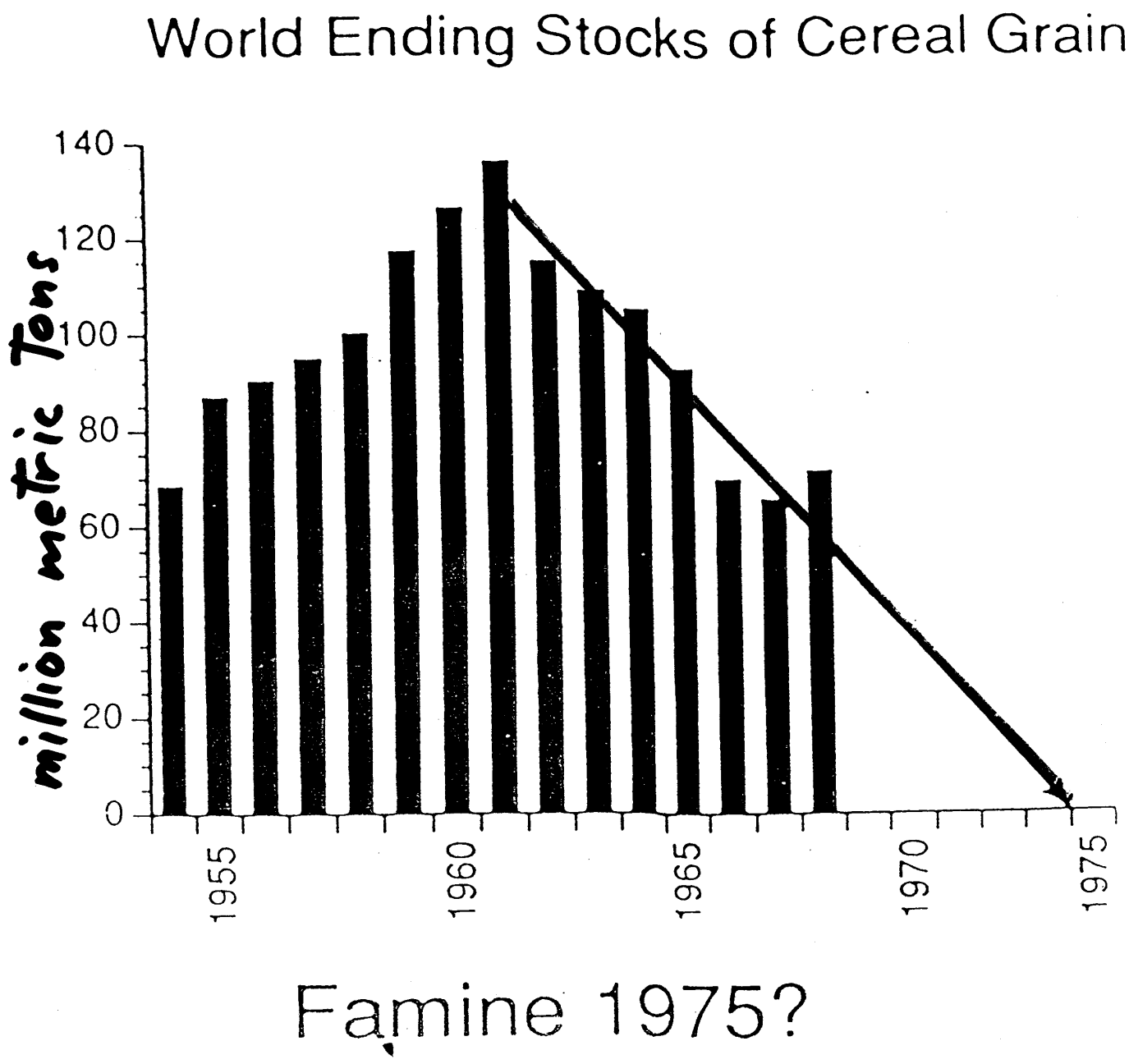
Massive chronic hunger, especially among children

Some causes of hunger

Some consequences of hunger

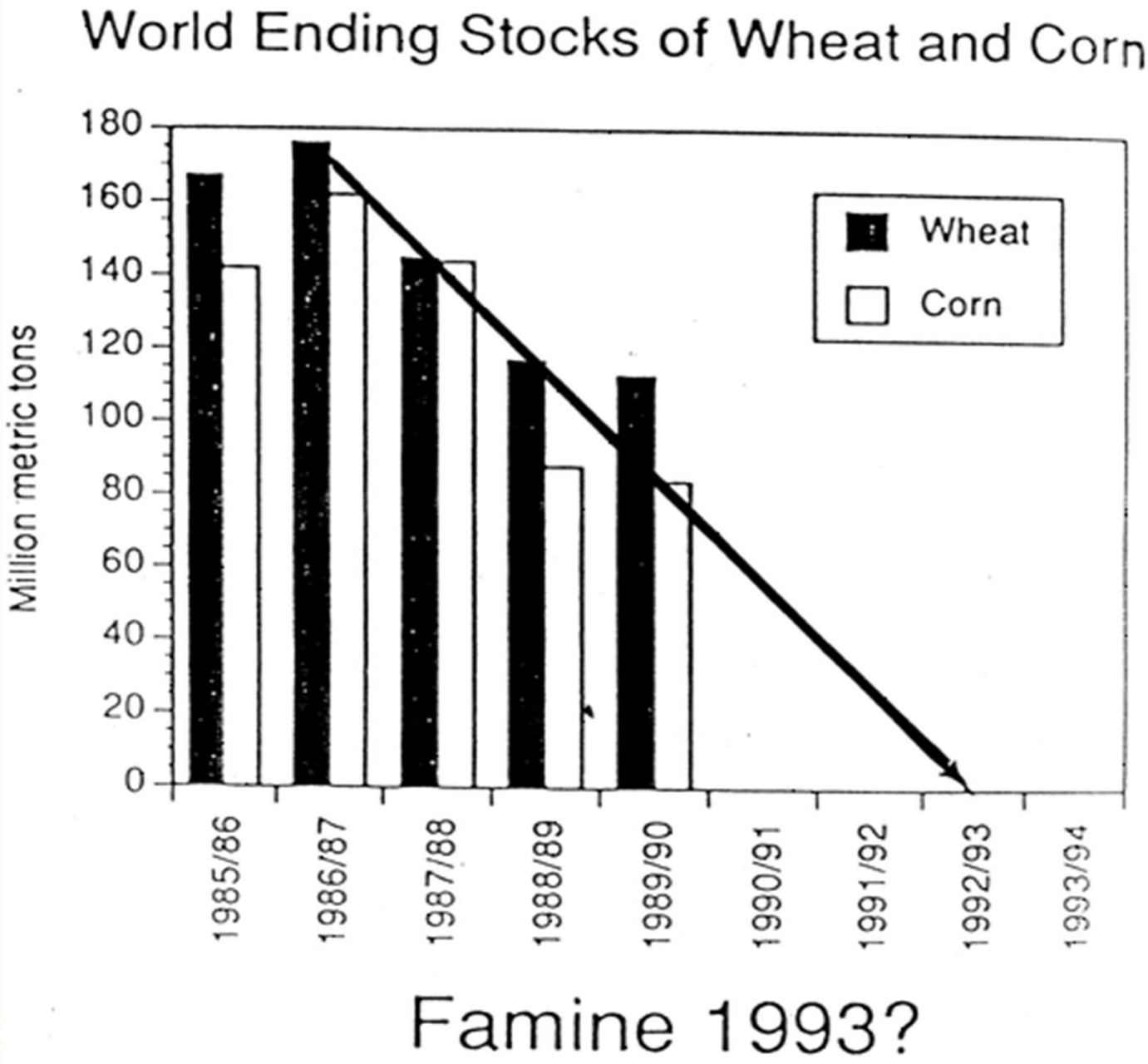
Actions to reduce hunger

FIGURE 8. World Cereal Grain Annual Carryover, 1954 to 1968



Famine 1975! America's Decision: Who Will Survive? 1967 by William & Paul Paddock

FIGURE 9. World Wheat and Corn Annual Carryover, 1986 to 1990



Food is superabundant.

BUSINESS NEWS | Tue Apr 11, 2017 | 11:10pm IST

Grains piled on runways, parking lots, fields amid global glut

Reuters

A mountain of grain sits in a storage pile, as midwestern grain farmers and merchants struggle to find storage space after three years of record harvests, near Minburn, Iowa, U.S., March 11, 2017. REUTERS/Scott Morgan

1/4

“World stockpiles of corn and wheat are at record highs.”

REUTERS BUSINESS NEWS Tue Apr 11, 2017 11:10pm IST

Farmers face similar problems across the globe. World stockpiles of corn and wheat are at record highs. From Iowa to China, years of bumper crops and low prices have overwhelmed storage capacity for basic foodstuffs.

Global stocks of corn, wheat, rice and soybeans combined will hit a record 671.1 million tonnes going into the next harvest - the third straight year of historically high surplus, according to the U.S. Department of Agriculture (USDA). That's enough to cover demand from China for about a year.

“Never has the world produced so much more food than can be consumed in one season.”

“A global grains glut is now in its fourth year, with supplies bloated by favorable weather, increasingly high-tech farm practices and tougher plant breeds.”

Reuters September 27, 2017 / 7:06 AM

Markets

Lack of Grain Storage Is Bad News for Midwest Farmers

The trifecta of tariffs, lackluster prices and near-perfect growing conditions means space is limited.

By David Fickling
October 4, 2018 18:30

The trade war is backfiring in Trump Country. *Photographer: Scott Olson/Getty Images North America*

2019-07-08

FAO, *World Food Situation*, 01 Nov 2018

Cereal grains 2017/18:
>2.6 billion tonnes production & use,
815 million tonnes ending stocks

How many grams of carbohydrate give your daily energy?

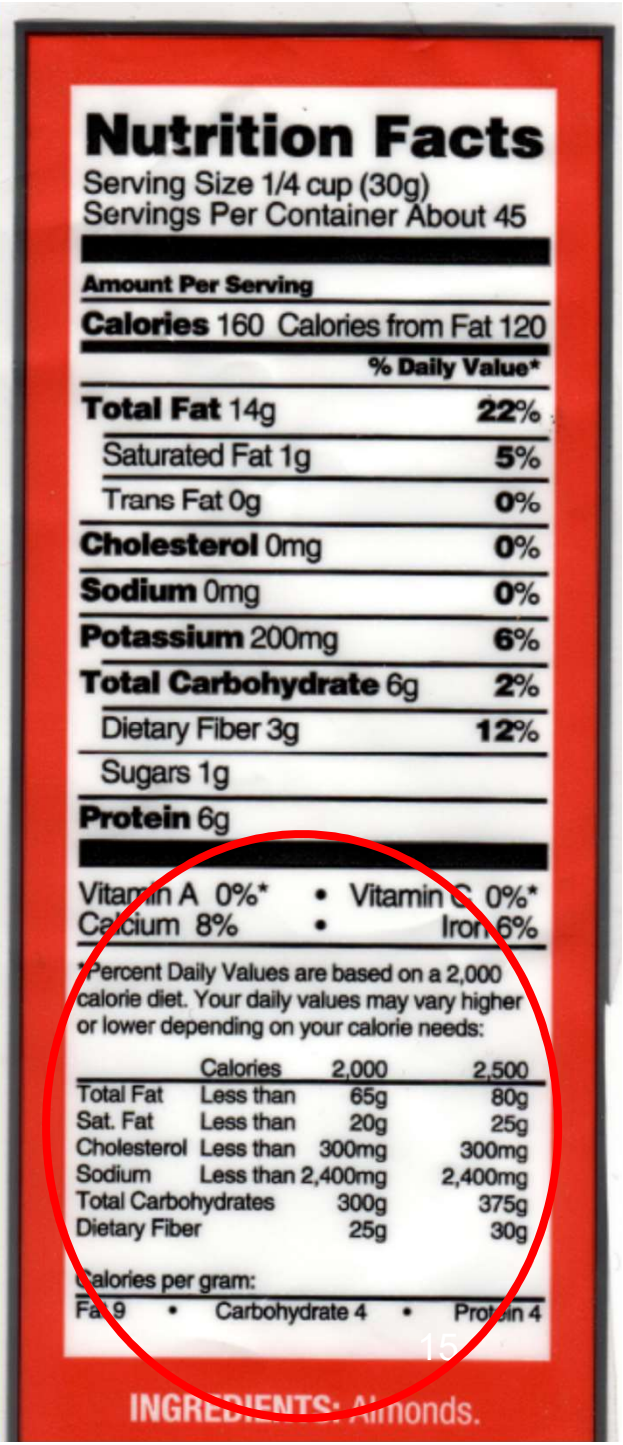
How many grams of carbohydrate give your daily energy?

*Percent Daily Values are based on a 2,000 calorie diet. Your daily values may vary higher or lower depending on your calorie needs:

	Calories	2,000	2,500
Total Fat	Less than	65g	80g
Sat. Fat	Less than	20g	25g
Cholesterol	Less than	300mg	300mg
Sodium	Less than	2,400mg	2,400mg
Total Carbohydrates		300g	375g
Dietary Fiber		25g	30g

Calories per gram:

Fat 9 • Carbohydrate 4 • Protein 4



How much carbohydrate gives your daily energy?

1 Calorie = 1,000 calories = 1 kcal.
1 kcal heats 1 kg (liter) water 1 degree C.

2000 kcal/day / 4 kcal/g
= 500 g/day = 0.5 kg/day carbohydrate

2500 kcal/day / 4 kcal/g
= 625 g/day = 0.625 kg/day carbohydrate

Your daily energy in watts

1 joule (J) per second = 1 watt

1 kcal = 4,184 joules

= 100 watts for 4.184 seconds

2000 kcal/day = 2000/24 kcal/hour

= 2000/(24x3600) kcal/second

= (4184x2000)/(24x3600) J/s = 97 watts

2500 kcal/day = 121 watts

How much carbohydrate gives your yearly energy?

How much carbohydrate gives your yearly energy?

Days in 1 year (d/y) = 365.25 ≈ 400.

If you use 2000 kcal/day, then energy/y
≈ 400 day x 2000 kcal/day = 800,000 kcal/y.

Yearly carbohydrates ≈ 400 day x 500 g/day
= 200,000 g/y = 200 kg/y = 1/5 mt/y carb.

If you use 2500 kcal/day, then energy/y
≈ 400 day x 2500 kcal/day = 1,000,000 kcal/y.

Yearly carbohydrates ≈ 400 day x 625 g/day
= 250,000 g/y = 250 kg/y = 1/4 mt/y carb.

1 mt carb feeds 4-5 people for 1 year.

1 mt carbohydrate provides energy needed by 4-5 people for 1 year.

1 tonne (1000 kg) of carbohydrate supplies enough energy for 4-5 people for 1 year.

200 kg of this grain provides	kilocalories per day for a year
Rice	2,000
Wheat pasta	2,032
Corn (maize)	1,984
Oatmeal	2,028

2.6 bln tonnes of cereal could feed 10-13 billion people.

Outline

Superabundant food

➔ Massive chronic hunger, especially among children

Some causes of hunger

Some consequences of hunger

Actions to reduce hunger

Chronic hunger is widespread.

Famine differs from chronic undernourishment.

Famine makes news.

Chronic hunger rarely makes news.

Childhood stunting measures chronic hunger.

Childhood wasting measures acute hunger.

Childhood underweight blurs chronic & acute hunger.

“Yemen at 'point of no return' as conflict leaves almost 7 million close to famine” The Guardian 2017-03-16

Reuters / Friday, September 09, 2016
A malnourished boy lies on a bed at a hospital in the Red Sea port city of Houdieda, Yemen.
USED WITH PERMISSION OF REUTERS

Houdieda, Yemen, Sept. 9, 2016.
REUTERS/Abduljabbar Zeyad
Used by permission.

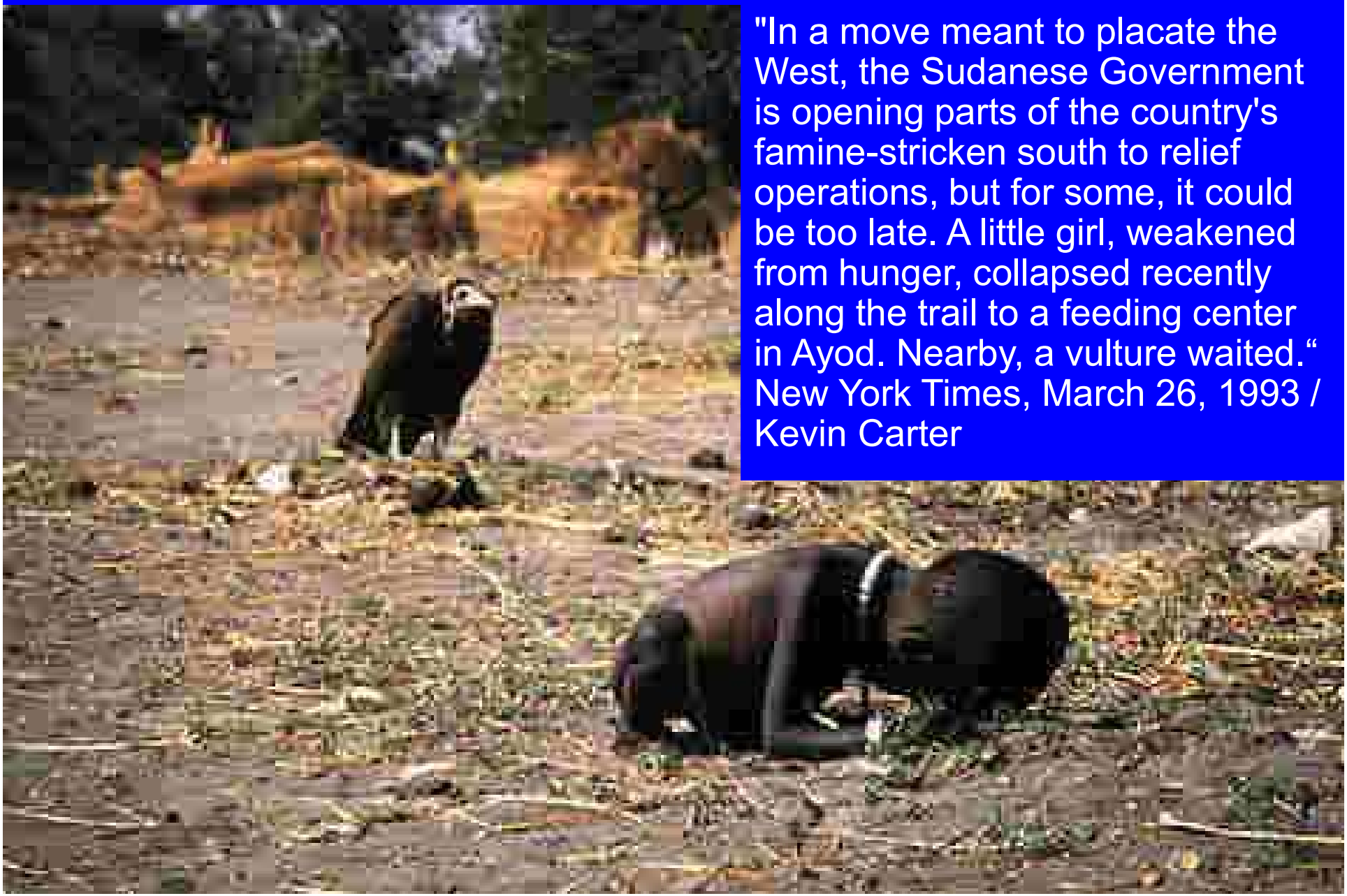

“Malnourished girl Jamila Ali Abdu, 7, lies on a hospital bed before she died in the Red Sea port city of Hodeidah, Yemen, May 2, 2017. REUTERS/ Abduljabbar Zeyad”

"Amal Hussain, 7, is wasting away from hunger. The Saudi-led war in Yemen has pushed millions to the brink of starvation. (Tyler Hicks for The New York Times)" Amal Hussain died the day after this picture was taken. https://www.wnycstudios.org/story/photographingstarving-children-yemens-war 2018-10-31

"Bassam Mohammed Hassan, who suffers from severe malnutrition and cerebral palsy, at a hospital in Sana, Yemen. (Tyler Hicks for The New York Times)“ https://www.wnycstudios.org/story/photographingstarving-children-yemens-war 2018-10-31

Kevin Carter

Sudan 1993

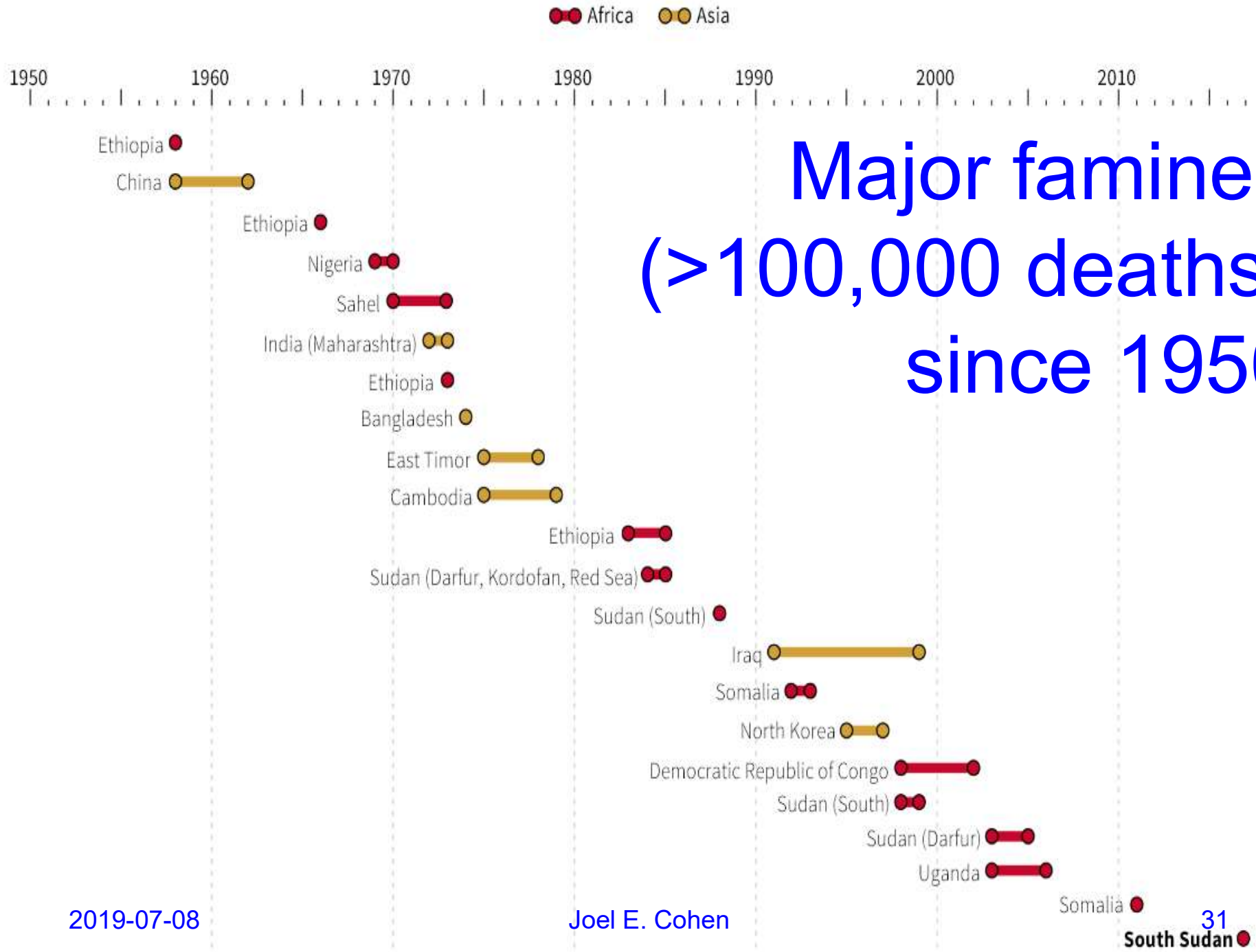


"In a move meant to placate the West, the Sudanese Government is opening parts of the country's famine-stricken south to relief operations, but for some, it could be too late. A little girl, weakened from hunger, collapsed recently along the trail to a feeding center in Ayod. Nearby, a vulture waited.“ New York Times, March 26, 1993 / Kevin Carter

These are famine victims.

Chronic undernutrition rarely makes news.

Major famines (>100,000 deaths) since 1950

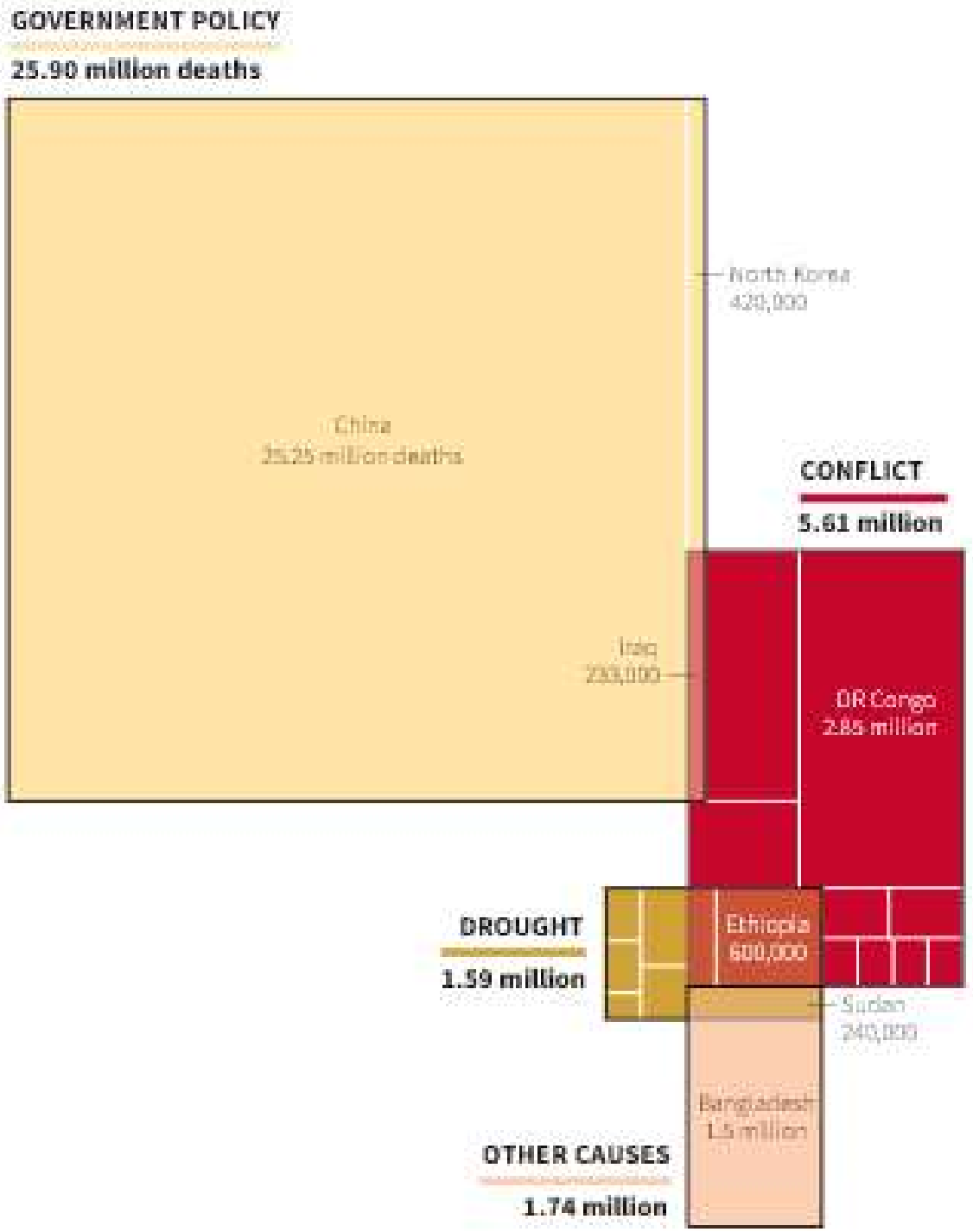


Reuters, *Slipping into famine* 2017-05-22; Tufts U World Peace Foundation

Government policy, conflict, drought, & flooding killed ~35 million in major famines since 1950.

Reuters, Slipping into famine 2017-05-22, Tufts U World Peace Foundation

2019-07-08



Chronic hunger

"Undernourishment or chronic hunger is the inability of persons to consume enough food sufficient to meet dietary energy requirements." Food & Agricultural Organisation

Chronically undernourished people in developing regions (Africa, Asia, Latin America & Middle East)

FAO 1992; WRI 1994

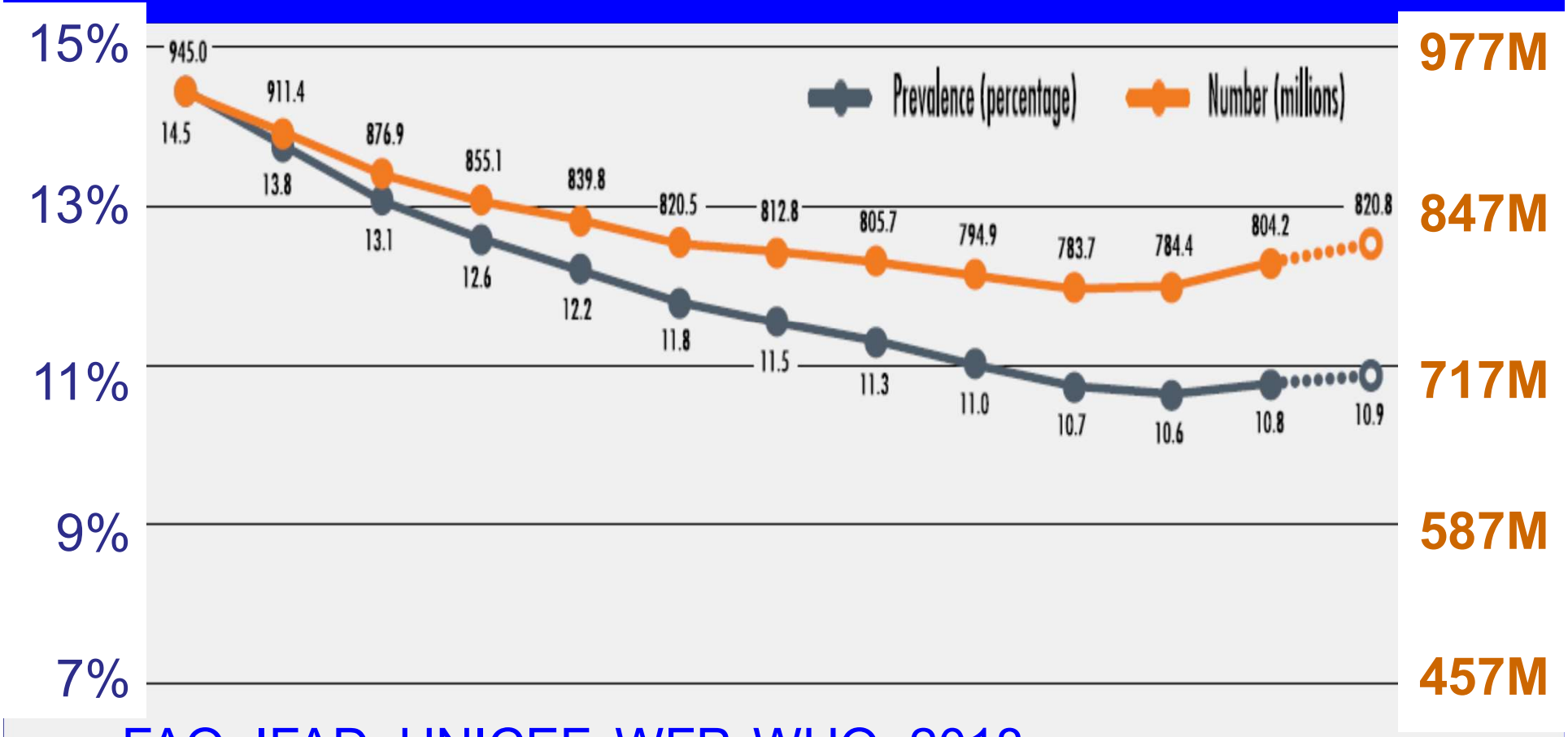
Years	people (millions)	% of region	% of world	Africa (mln)
1969-71	941	36	25	101
1979-81	844	26	19	128
1988-90	786	20	15	168
1994-96	828	18	19	210
1999-2001	798	17	13	204

Till recently, chronically undernourished population fell.

Region	1990-92	2014-16
World millions	1011	795
World percent	18.6%	10.9%
Developing regions millions	991	780
Developing regions percent	23.3%	12.9%

FAO, IFAD, WFP, *The State of Food Insecurity in the World 2015*

Global number of chronically undernourished rose since 2014.



FAO, IFAD, UNICEF, WFP, WHO 2018

State of Food Security and Nutrition in the World 2018

4 dimensions of food security

Physical availability

production, stocks, trade

Economic & physical access

income, prices, markets, transfer, infrastructure, household distribution

Use

food & nutrition knowledge, preparation, conservation, health, hygiene, care

Stability of other 3 dimensions

Poorer people spend higher % of their household budget on food.

Engel's law (1857, International Statistical Institute Bulletin 1895)

In human diets, food expenditures increase with income & family size, but the ratio of food expenditures to all expenditures decreases with increasing income.

Roughly, food expenditures ~ log(income), so the ratio

food expenditures /total expenditures

~ log(income)/income falls as income rises.

Poorer people eat more cereals & potatoes, so prices matters more.

Bennett's law (Geographical Review 1941)

In human diets, the lower household or national income, the higher the ratio of calories derived from cereals (wheat, rye, rice, barley, oats, corn, millets, & grain sorghums) & potatoes (white potatoes, sweet potatoes, and cassava).

➔ Meat consumption & protein quality rise as income rises.

Economic approaches: "food insecurity"

- People (#, %) living on <USD1.08/day at 1993 purchasing power parity prices (WB)
- People (#, %) with food intake below minimum level of dietary energy requirements (FAO "prevalence of undernourishment", based on food supply, consumption, & energy needs)
- Food Insecurity Experience Scale (FIES) (FAO, based on adult interviews)
- Low-income food-deficit countries (FAO)

Measures of chronic hunger vary.

Region, June 2009	"undernourished" FAO	"food insecure" USDA
World	1020 million	833 million
Asia	642 million	379 million
Sub-Saharan Africa	265 million	385 million

Barrett, *Science* 2010

Body mass index (BMI)

BMI = weight (kg) / height^2 (m^2)

For adults, WHO defines:

Obese: BMI ≥ 30

Overweight: BMI ≥ 25

Underweight: BMI ≤ 20

These definitions are useful for population summaries more than for individuals.

WHO uses other standards for children <5 y old & 5-19 y old.

4 anthropometric measures of hunger in children

Stunting: short height for age (chronic)

Wasting: low weight for height (acute)

Underweight: low weight for age (either/both)

Mid-upper arm circumference (MUAC): circumference of left upper arm midway between tip of shoulder (acromion) & tip of elbow (olecranon process) – best predictor of death

Child may be stunted & overweight, or stunted & wasted.

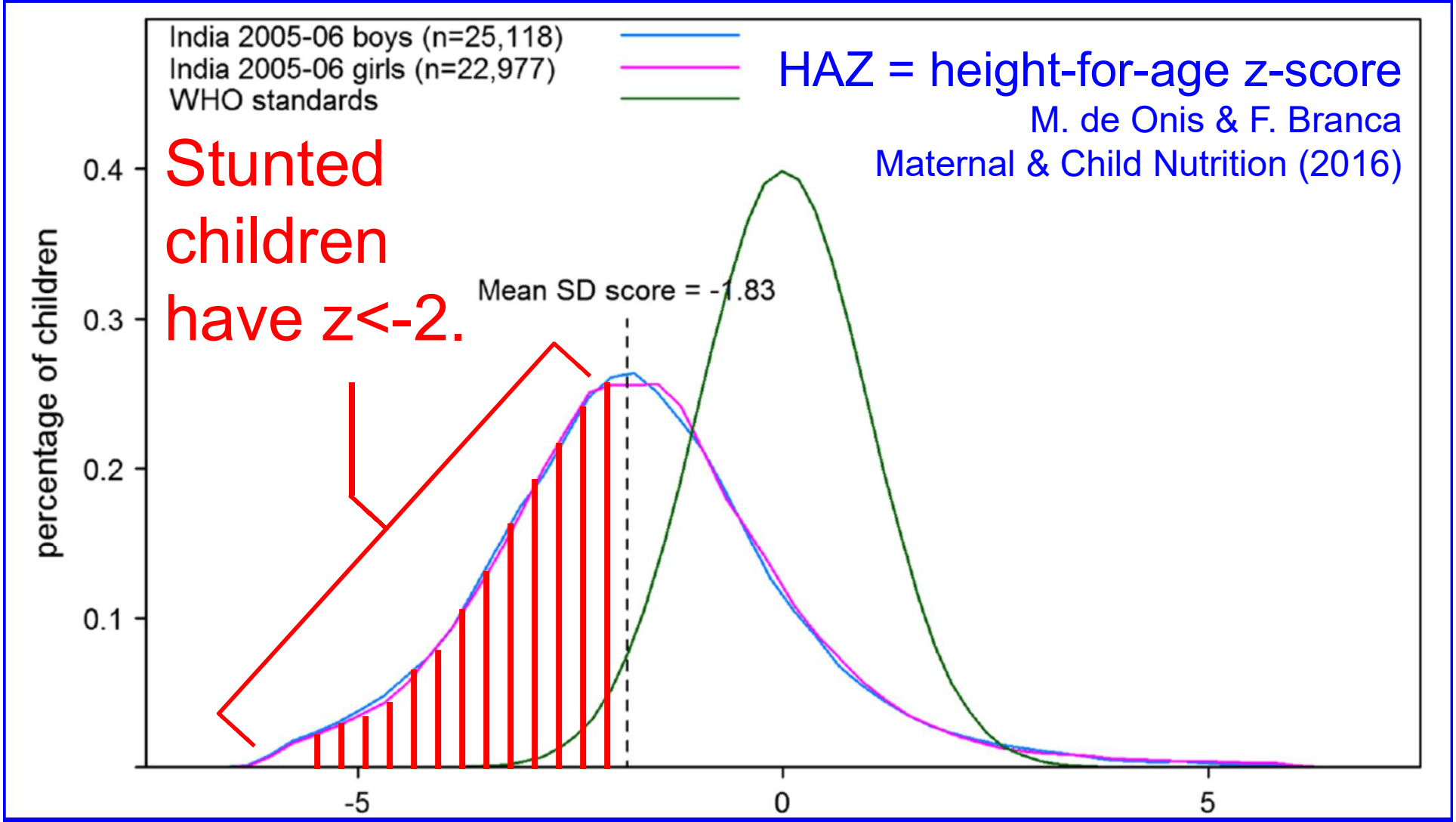
World Health Organisation Multicentre Growth Reference Study

6 years in 6 sites: Davis, California; Muscat, Oman; Oslo, Norway; Pelotas, Brazil; Accra, Ghana; South Delhi, India.

Growth was measured weekly up to 1 y, then monthly, then bimonthly, on 8440 affluent, healthy, well-nourished, breastfed children from middle-class backgrounds, with no maternal smoking.

Infants & young children grew similarly, regardless of race or ethnicity.

Example: stunting in India



z-score = standard deviations from median for age

Stunting

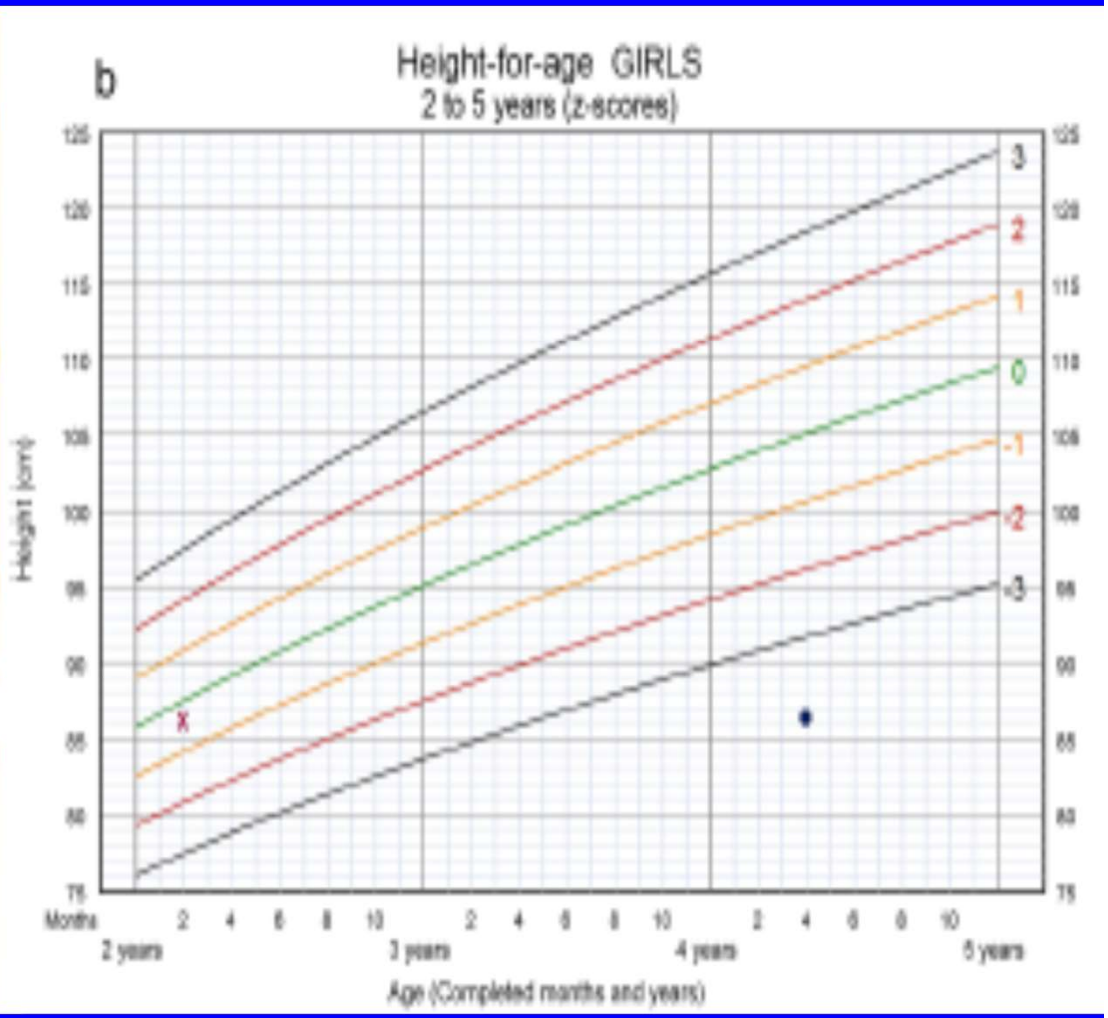
Stunting indicates chronic undernutrition and/or chronic infection.

Child suffers "stunting" if height of child falls below 2 standard deviations below median height of child of that age by WHO Child Growth Standards.

WHO Nutrition Landscape Information System

Stunting is not obvious to eye.

2 girls in Maldives



M. de Onis & F. Branca *Maternal & Child Nutrition* (2016)

Guatemala: 45.7% of children under 5 y were stunted, 2017.

European Commission

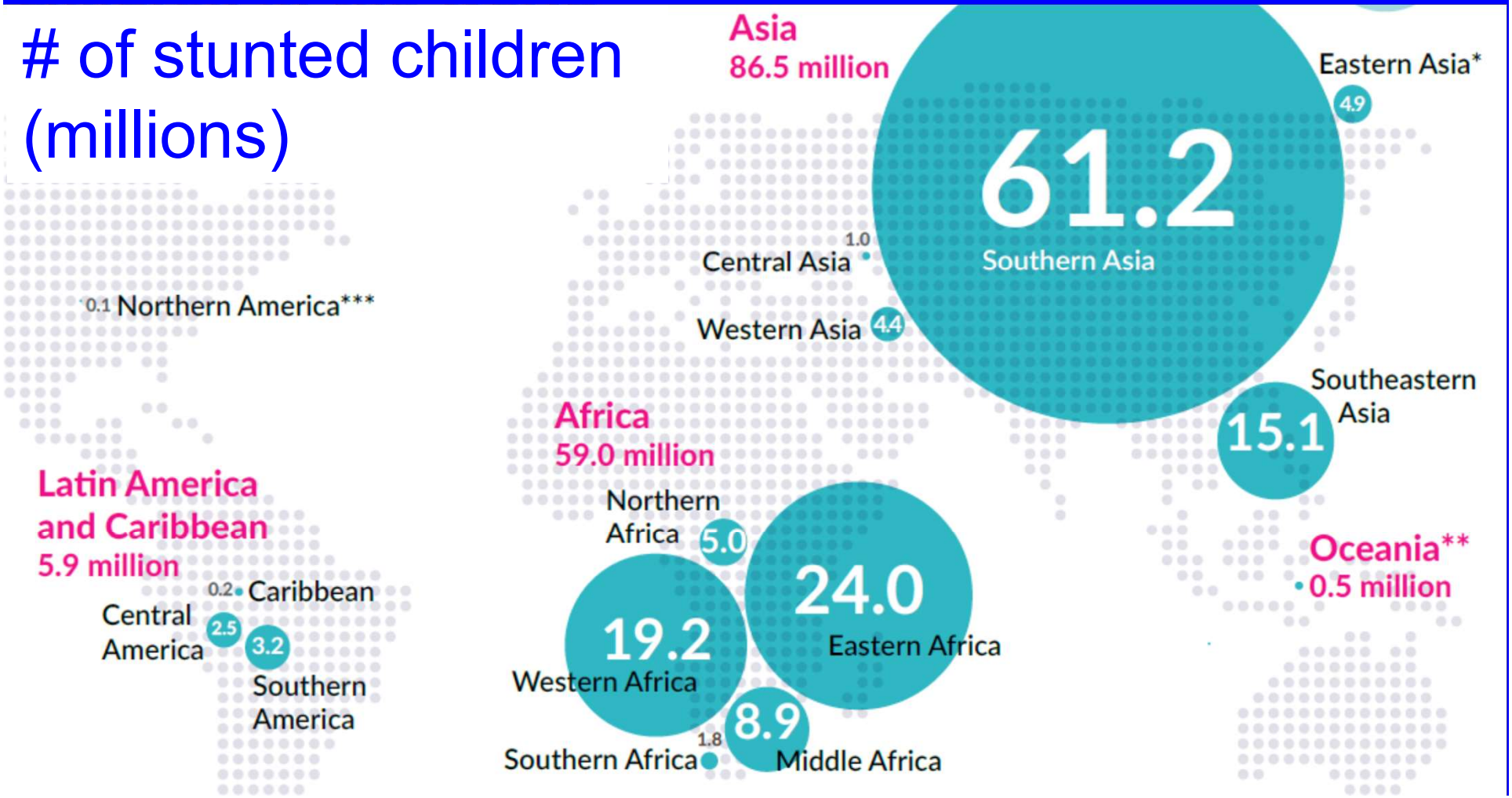
151 million children <5 were stunted in 2017.

Global stunting of children 0-4
fell from 29.5% in 2005
to >22%, still nearly ¼, in 2017.

FAO, IFAD, UNICEF, WFP, WHO 2018
The State of Food Security and Nutrition in the World 2018.

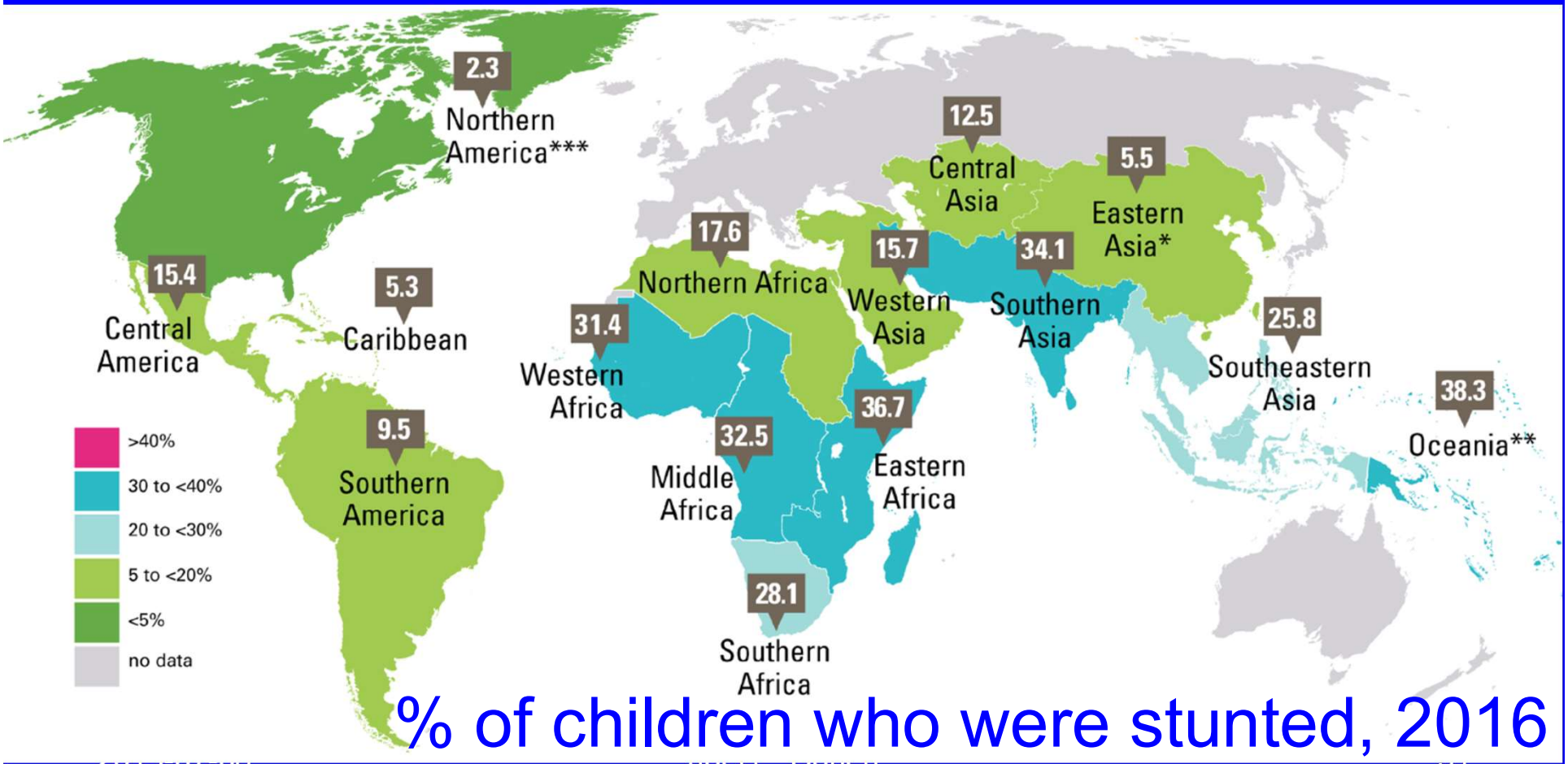
2/5 of stunted children live in southern Asia (155 million, 2016).

FAO, IFAD, UNICEF, WFP, WHO 2017



% of children 0-4 stunted was highest in S. Asia & E. Africa.

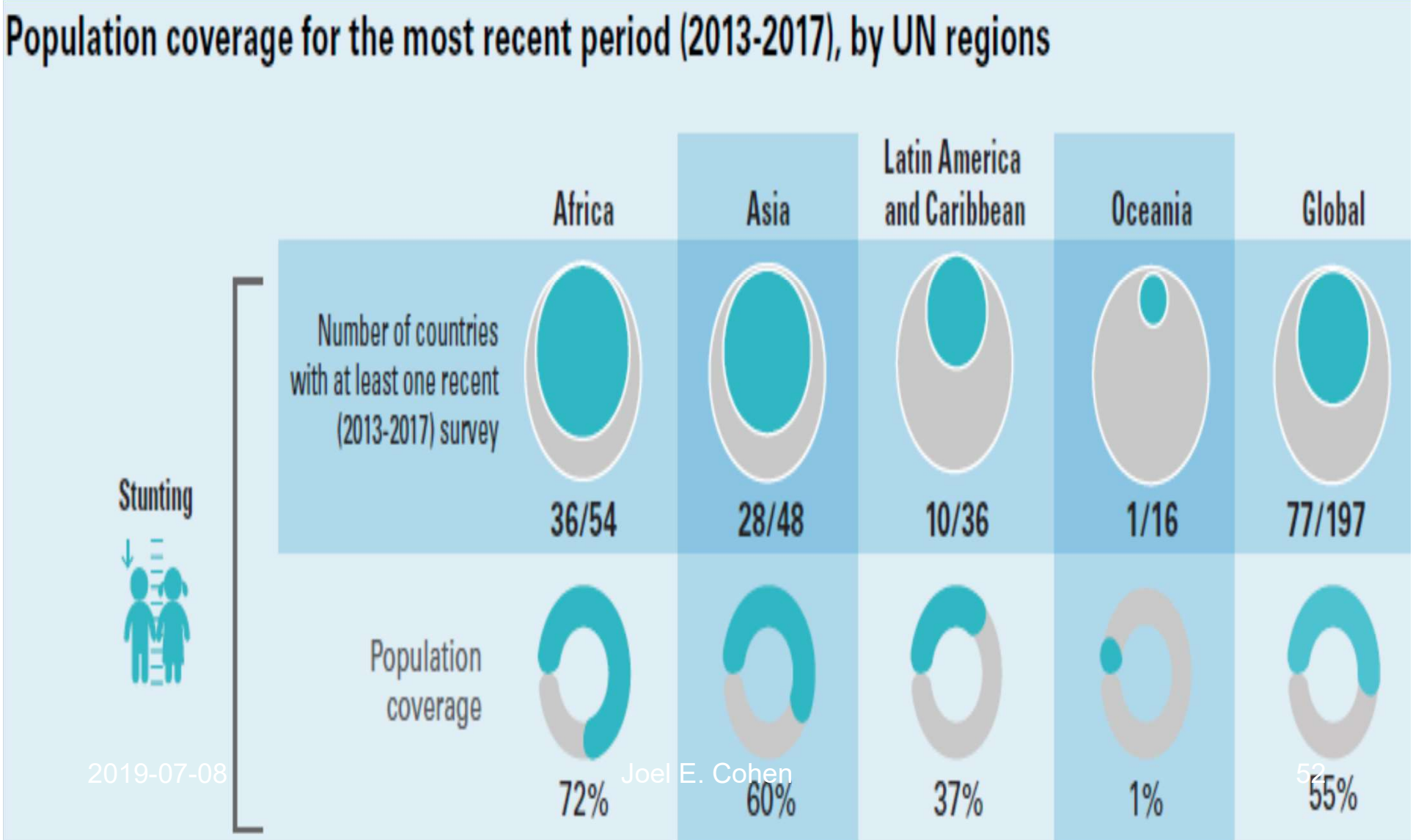
FAO, IFAD, UNICEF, WFP, WHO 2017



% of children who were stunted, 2016

How good are these numbers?

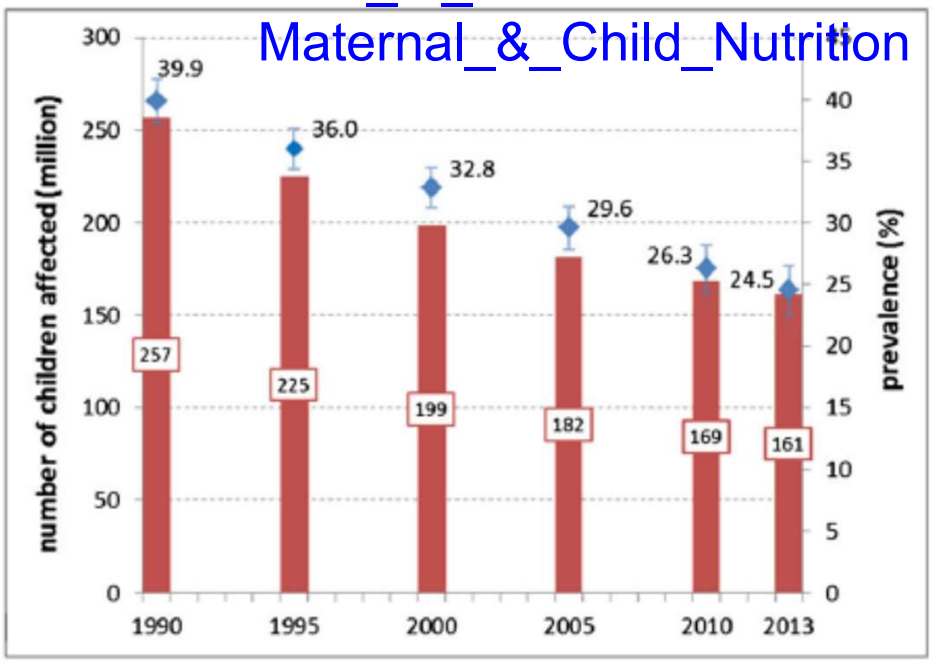
FAO, IFAD, UNICEF, WFP, WHO 2017

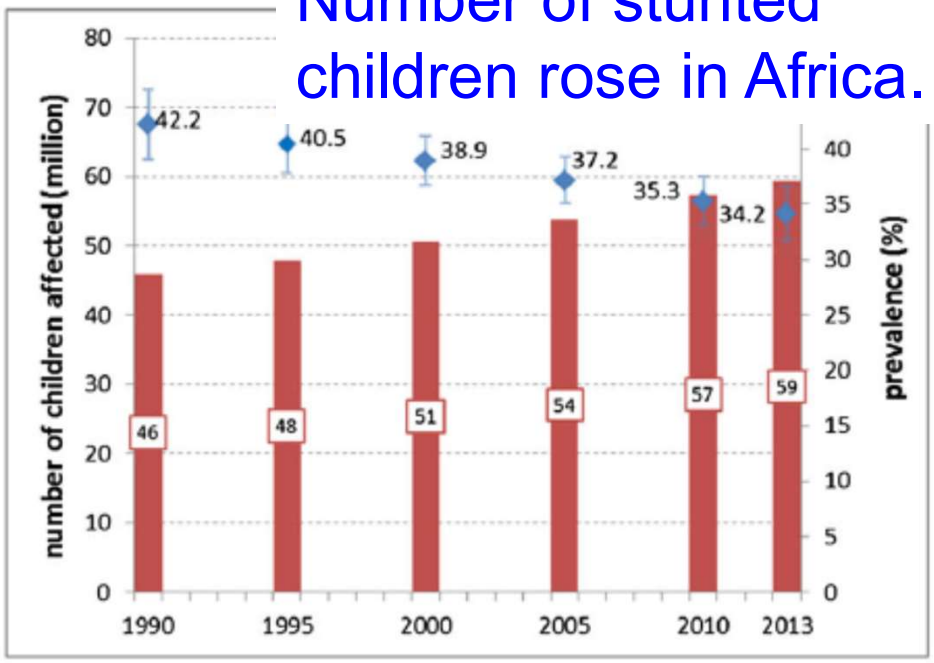


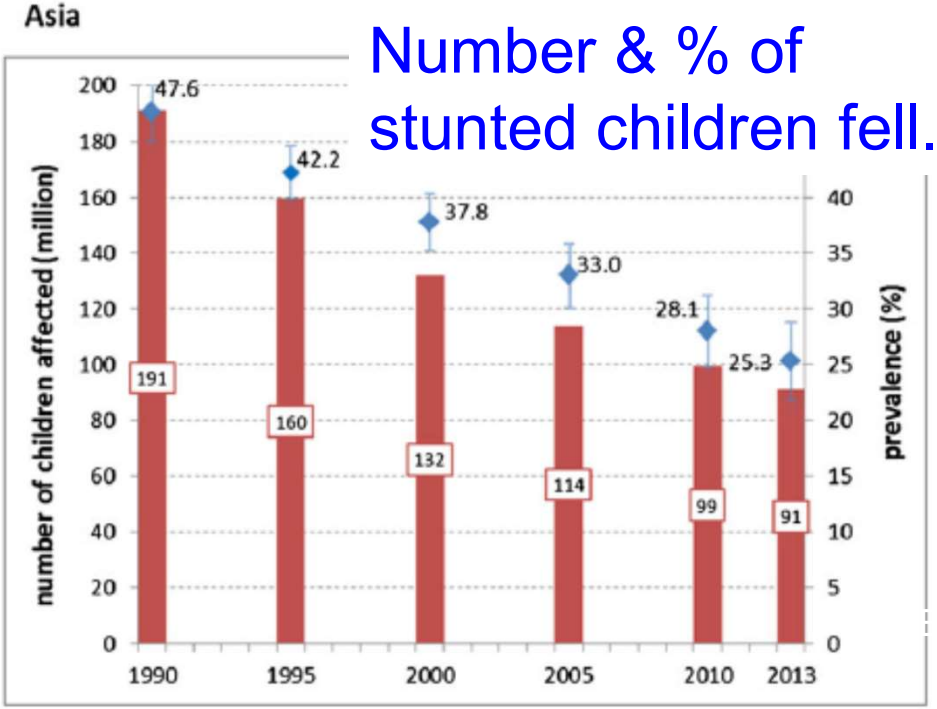
Onis_et_al-2016
Maternal_&_Child_Nutrition

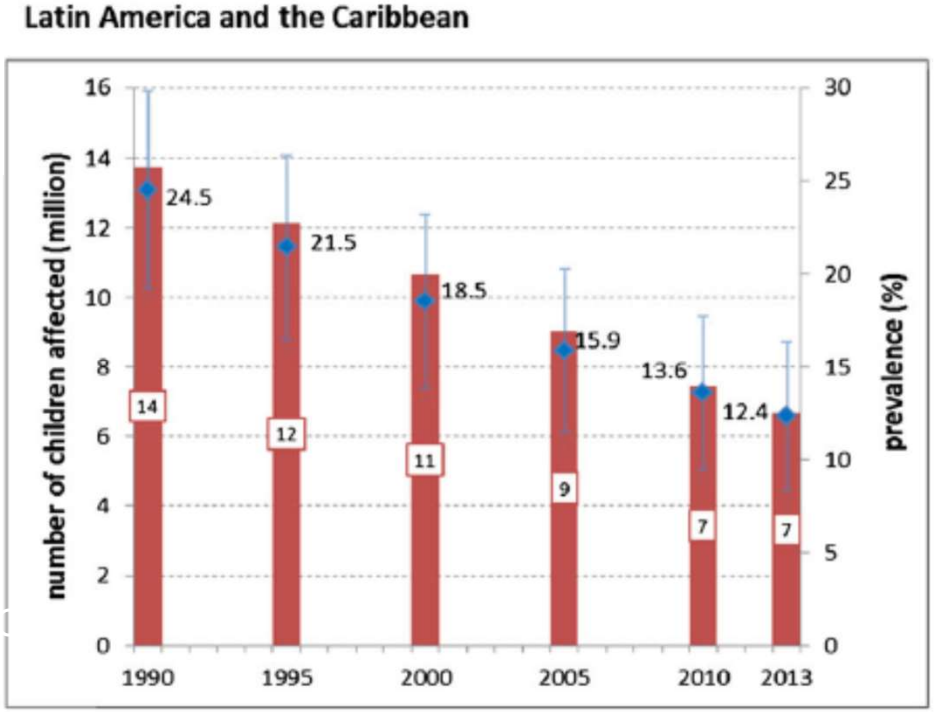
Number of stunted children rose in Africa.

Number & % of stunted children fell.









Outline

Superabundant food

Massive chronic hunger, especially among children

➔ Some causes of hunger

Some consequences of hunger

Actions to reduce hunger

Basic, underlying, & immediate causes of hunger

WHO conceptual framework

WHO/NMH/NHD/17.7 2017

Community & national context

WHO conceptual framework

Political economy

- Food prices and trade policy
- Marketing regulations
- Political stability
- Poverty, income and wealth
- Financial services
- Employment and livelihoods

Agriculture and food systems

- Food production and processing
- Availability of micronutrient-rich foods
- Food safety and quality

Water, sanitation and environment

- Water and sanitation infrastructure and services
- Population density
- Climate change
- Urbanization
- Natural and manmade disasters

Health and healthcare

- Access to healthcare
- Qualified healthcare providers
- Availability of supplies
- Infrastructure
- Health care systems and policies

Society and culture

- Beliefs and norms
- Social support networks
- Child caregivers (parental and non-parental)
- Women's status

Education

- Access to quality education
- Qualified teachers
- Qualified health educators
- Infrastructure (schools and training institutions)

WHO/NMH/NHD/17.7

Household context WHO conceptual framework

The home

- Inadequate sanitation and water supply
- Low wealth and socioeconomic status
- Food insecurity
- Low status of women
- Low caregiver education
- Inappropriate intra-household food allocation

Number of siblings

Poor quality foods

- Poor micronutrient quality
- Low dietary diversity and intake of animal-source foods
- Anti-nutrient content
- Low energy content of complementary foods

Food and water safety

- Contaminated food and water
- Poor hygiene practices
- Unsafe storage and preparation of foods

Infection

- Enteric infection: Diarrhoeal disease, environmental enteropathy, helminths
- Respiratory infections
- Malaria
- Reduced appetite due to infection
- Inflammation

The mother

- Poor nutrition during pre-conception, pregnancy and lactation
- Short maternal stature
- Infection
- Adolescent pregnancy
- Short birth spacing
- IUGR and preterm birth
- Poor mental health
- Hypertension

Inadequate care

- Poor care practices
- Inadequate child stimulation and activity
- Non-responsive feeding

Inadequate breastfeeding

- Delayed initiation
- Non-exclusive breastfeeding
- Early cessation of breastfeeding

Inadequate complementary feeding

- Infrequent feeding
- Inadequate feeding during and after illness
- Thin food consistency
- Feeding insufficient quantities

WHO/NMH/NHD/17.7

Stunting often starts before birth.

In Indian children <5, 44%-55% (depending on survey year) of growth faltering was present at birth.

Malawi: 20% of 10-cm deficit in height at 3 y was present at birth.

19 birth cohorts: 20% of stunting originated in utero.

M. de Onis & F. Branca *Maternal & Child Nutrition* (2016)

Being small for gestational age at full term is major proximal risk factor for stunting.

Of 18 proximal risk factors in 44.1 million cases of stunting among 2-year-olds in 137 developing countries, the leading risk was "term, and small for gestational age" (10.8 million) followed by poor sanitation (7.2 million) & diarrhea (5.8 million).

Danaei, Andrews, Sudfeld, et al. (2016)
PLoS Med 13(11): e10021

Maternal education influences stunting.

In South Africa, more maternal education was strongly associated with reduced child stunting. Casale et al. 2018 Public Health Nutrition

41% of the effect of maternal education on stunting was due to socio-economic status (assets, parental occupation); another 18% due to child's birth weight: "… education improves the ability of the mother to foster a healthy environment for the child's intra-uterine growth."

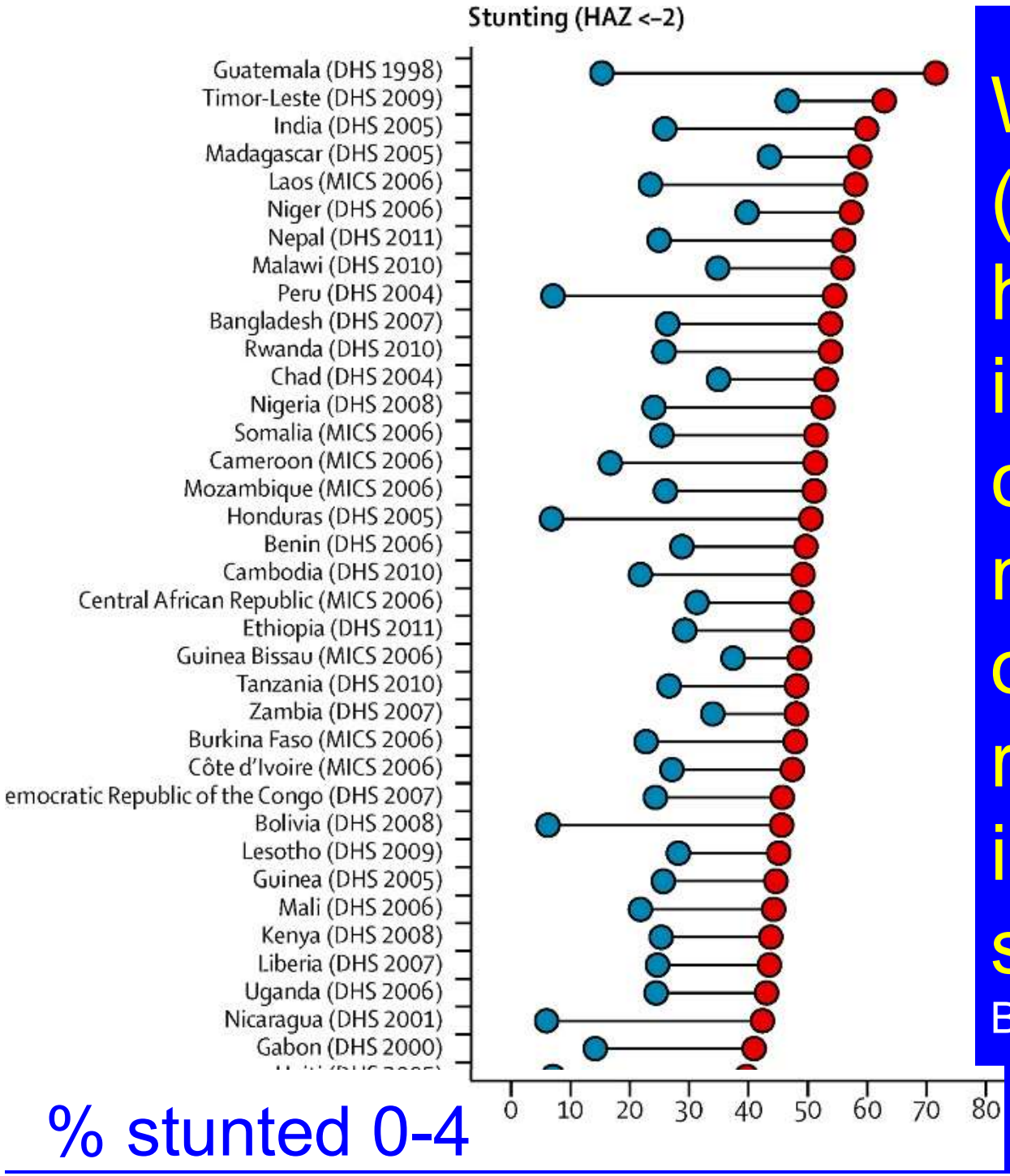
Other possible factors contributing to child stunting

Mismatch between location of grain production & location of children

Government policies

Environment (droughts, floods)

Lack of money ("access" in economics)



Wealth quintile (lowest=red, highest=blue) influences child stunting more than sex or urban-rural residence influences stunting.

Black et al. *Lancet* 2013

Poverty influences wasting more than mother's education, gender, or urban v. rural residence.

FAO, IFAD, UNICEF, WFP and WHO 2018 The State of Food Security and Nutrition in the World 2018

Hungry people are absent from grain markets.

Lack of effective demand, i.e., demand supported by customers' orders and capacity to pay, for sufficient food contributes to widespread undernutrition of adults and children.

~800 million chronically undernourished people exercise less demand than those who demand meat, biofuels, & other non-food uses of grain.

The world uses >2.5 billion tonnes/year of cereal grains, but only 43% feeds people.

FAO GIEWS Food Outlook Nov 2017

Use 2016-17	Million metric tons	%
Food	1,103	43
Feed	905	35
Other	561	22
Total use	2,569	100

Markets serve people with money.

A market works only for people with enough money to pay for what the market offers. One must pay to play in grain markets. People with insufficient money are excluded from markets.

Absent public or private social safety nets, poor people at the bottom of the income distribution do not satisfy the assumptions of the economic theory of markets.

Outline

Superabundant food

Massive chronic hunger, especially among children

Some causes of hunger

➔ Some consequences of hunger

Actions to reduce hunger

Demographic & economic consequences of hunger

Consequences for child & adult

WHO conceptual framework

Concurrent problems and short-term consequences

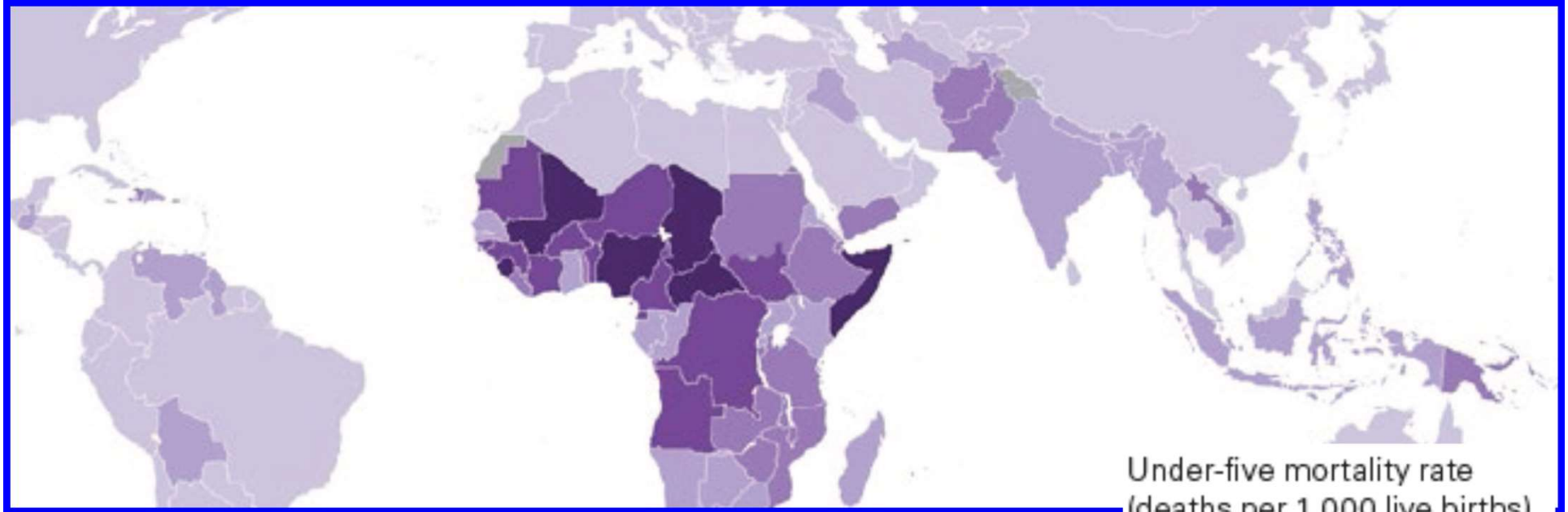
- **Health:** ↑ Mortality, ↑ Morbidities
- **Developmental:** ↓ Cognitive, motor, and language development
- **Economic:** ↑ Health expenditures, ↑ Opportunity costs for care of sick child

Long-term consequences

- **Health:** ↓ Adult stature, ↑ Obesity and associated co-morbidities, ↓ Reproductive health
- **Developmental:** ↓ School performance, ↓ Learning capacity, Unachieved potential
- **Economic:** ↓ Work capacity, ↓ Work productivity

Almost half [45%] of deaths 0-4 are associated with undernutrition.

Black et al. *Lancet* 2013

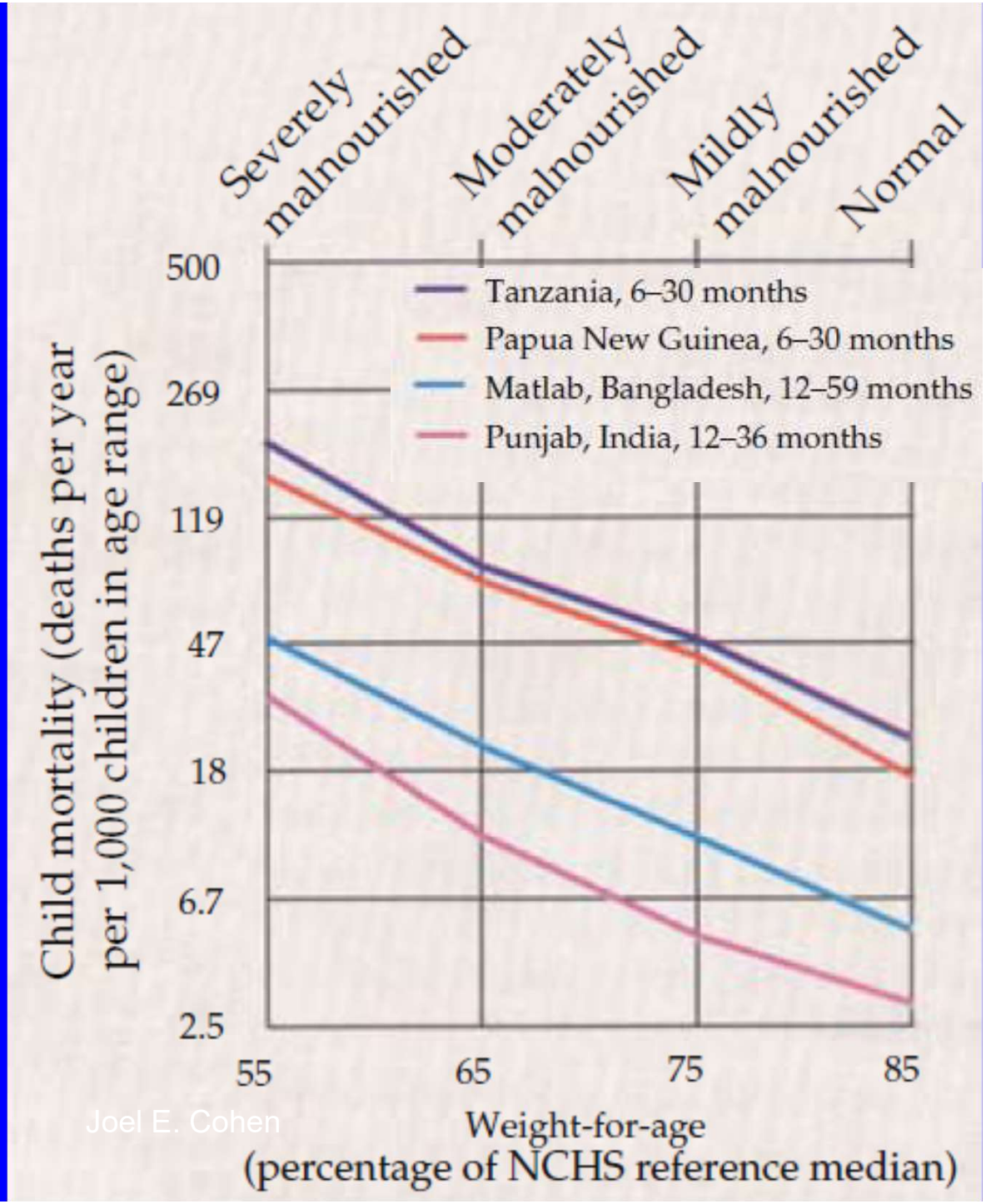


Map from UNICEF, *Levels & Trends in Child Mortality Report 2018.* Estimates by UN Inter-agency Group for Child Mortality Estimation

2019-07-08

Joel E. Cohen

Underweight children have higher risk of death.



Pelletier, 1991

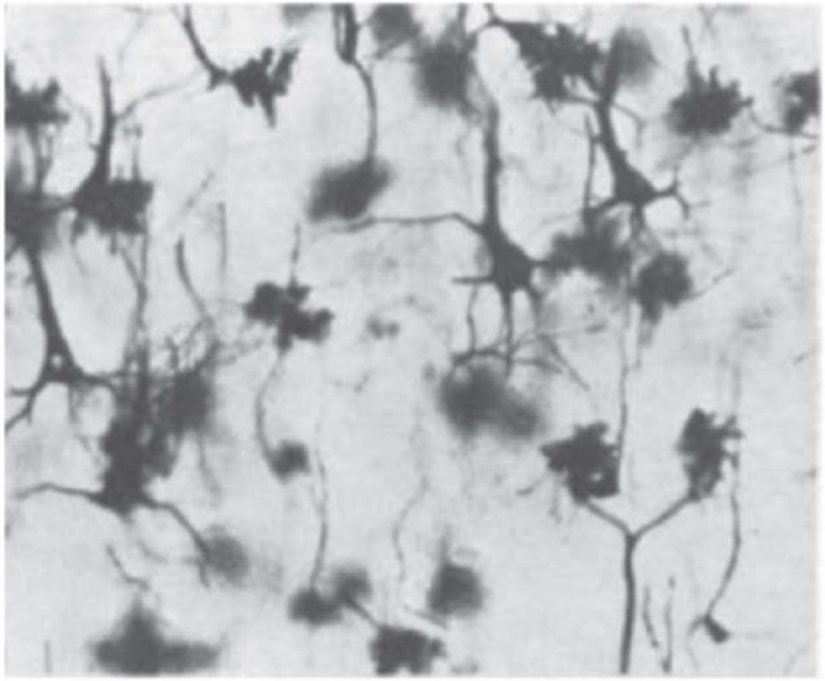
Undernourishment alters brain.

M. de Onis & F. Branca 2016 from Cordero et al. 1993

Well-nourished infant

Typical brain cells
Extensive branching

Undernourished infant



Impaired brain cells
Limited branching
Abnormal, shorter branches

Stunting threatens human development.

"The severe irreversible physical and neurocognitive damage that accompanies stunted growth poses a major threat to human development."

Mercedes de Onis, Francesco Branca

Maternal & Child Nutrition 2016

Stunting impedes schooling.

"Stunting … often results in delayed mental development, poor school performance and reduced intellectual capacity. This in turn affects economic productivity at national level."

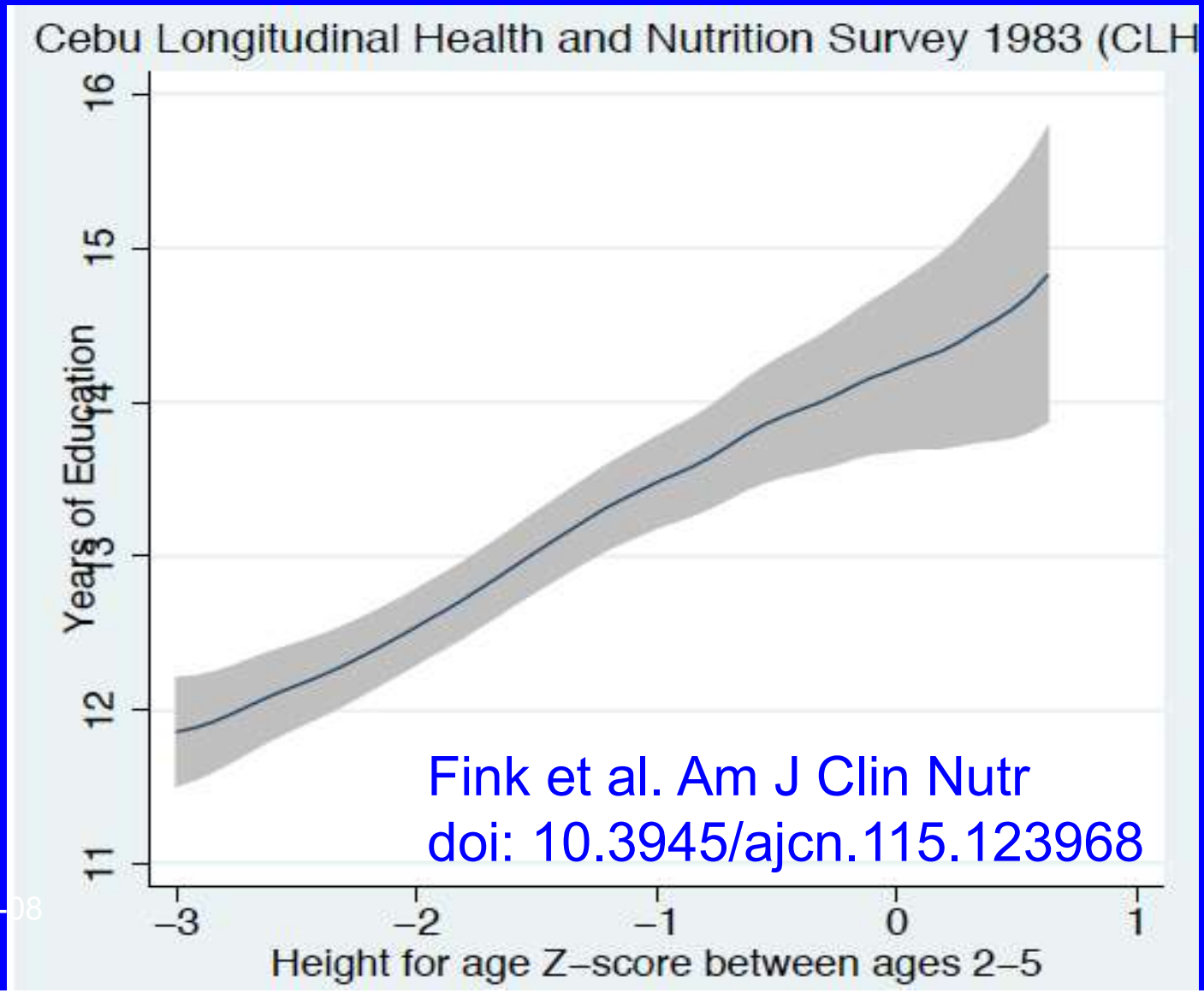
WHO Nutrition Landscape Information System

India: child height age 8-11 is associated with ability to write.

In Indian Human Development Survey of 40,000 households 2004-05, among children 8-11 y, increase in height-for-age z-score by one standard deviation increased likelihood of being able to write by 5 percentage points, & by 3.4 percentage points after controlling for confounders, especially water, sanitation, & hygiene.

Spears 2012 *Econ & Human Biol*

Philippines: height-for-age Z-score predicts years of education.



Fink et al. Am J Clin Nutr
doi: 10.3945/ajcn.115.123968

4 rural Guatemalan villages

community-randomized food-supplementation trial 1969–1977
follow-up data 2002–2004

At 24 mo of age, mean HAZ < -3, 86% stunted. "… individuals who were stunted suffered profound adverse consequences in adulthood."
Scored worse on reading & intelligence tests.
Matched with poorer-quality partners measured by grade attainment & height.
Women had their first child at younger ages, had more pregnancies, had more children.
More likely to live in poor households as adults.
Men but not women had lower wage rates.

Hoddinott *et al. Am. J. Clin. Nutrition* 2013

Developmental origins of health & disease or life course epidemiology

"A poor start to life is associated with an increased risk for a number of disorders, especially non-communicable diseases in later life. These disorders include cardiovascular disease, obesity, type 2 diabetes and metabolic disturbances, osteoporosis, chronic obstructive lung disease, some forms of cancer, and mental illnesses."

Developmental Origins of Health & Disease,
9th World Congress 2015

Overview

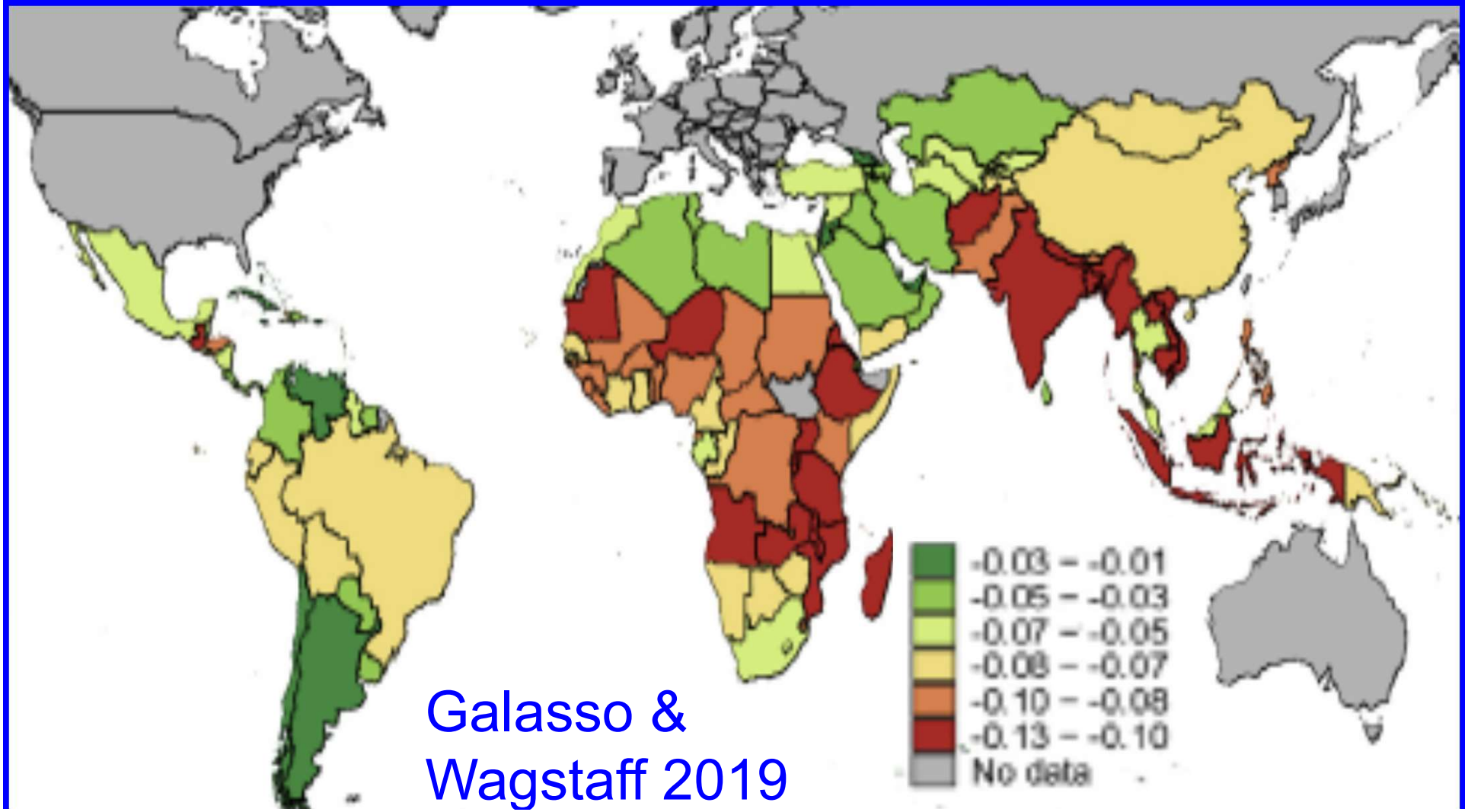
1. Stunting
2. Outcomes & costs
3. Feedbacks from outcomes to causes
4. Causes & context

Stunting in childhood of people working in 2014 lowered income/person by 5-7% in 140 developing countries compared to no stunting.

Mean reduction in income/person due to stunting was 9% in 47 countries of sub-Saharan Africa & 8 countries of south Asia.

Galasso & Wagstaff, *Economics and Human Biology* 2019

Effects of childhood stunting on income per person of 2014 workers



Galasso & Wagstaff 2019

Effects of stunting considered:

Galasso & Wagstaff, *Economics and Human Biology* 2019

1. Reduced years of schooling;
2. Reduced adult height;
3. Reduced cognitive capacity (score on cognitive test, measured in standard deviations from a mean).

IGNORED:

Reduced survival;

Reduced health.

How was reduction estimated?

The current income of current workers was reduced by income returns to a year of education applied to the reduction in years of education from childhood stunting; & by returns to an increment of adult height applied to reduction in adult height; & by the returns to cognitive skills applied to reduction in cognitive skills.

Galasso & Wagstaff, 2019

Limitations of analysis imply that real reduction may be >7%.

Omitted effects on survival & health.

Assumed Cobb-Douglas production function with constant residual total factor productivity (scale factor, RTFP) & constant physical capital.

More educated & more skilled workers could better adopt & create new technology, changing RTFP & capital stock.

Firms' decisions to adopt new technology could be affected by the availability of workers with more education and skills.

Galasso & Wagstaff, 2019

Outline

Superabundant food

Massive chronic hunger, especially among children

Some causes of hunger

Some consequences of hunger

➔ Actions to reduce hunger

Some nutritional interventions to reduce stunting

Nutrition-specific

- Breastfeeding promotion
- Iodine supplementation
- Multiple micronutrients (vitamins, Fe)
- Supplementary feeding

Nutrition-sensitive

- Water, sanitation, hygiene (WASH)
- De-worming

To reduce stunting, improve:

M. de Onis & F. Branca *Maternal & Child Nutrition* (2016)
FAO, IFAD, UNICEF, WFP, WHO. 2017.
The State of Food Security and Nutrition in the World 2017.

food & nutrition security
water, sanitation & hygiene
education
health (infection, anemia)
income
status of women
law & institutions
conflict resolution

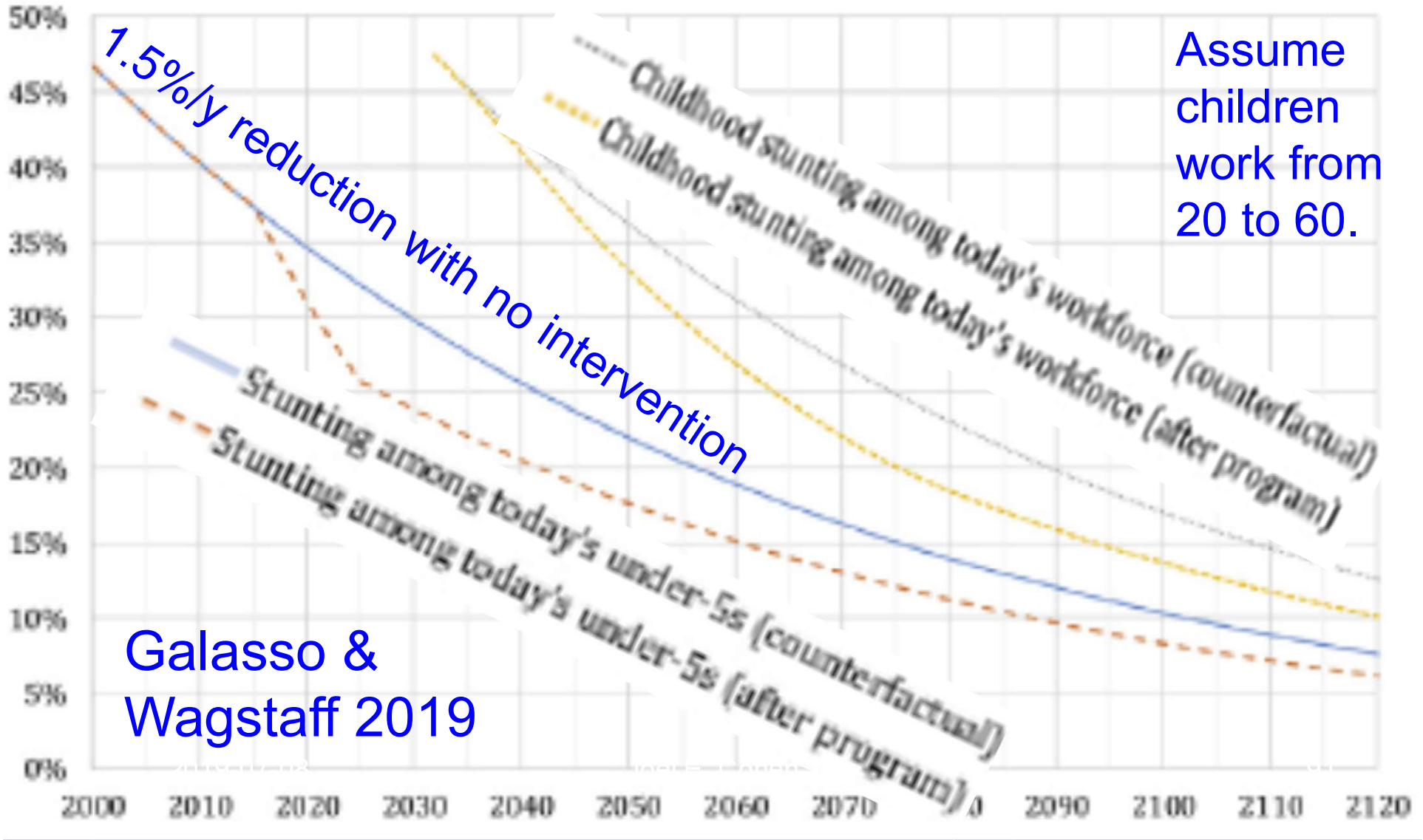
Bhutta et al. 2013 interventions

Galasso & Wagstaff, *Economics and Human Biology* 2019

(i) salt iodization ($68 m),
(ii) multiple micronutrient supp. in pregnancy including iron-folate ($472 m),
(iii) calcium supp. in pregnancy ($1914 m),
(iv) energy-protein supp. in pregnancy ($972 m),
(v) vitamin A supp. in childhood ($106 m),
(vi) zinc supp. in childhood ($1182),
(vii) breastfeeding promotion ($653 m),
(viii) complementary feeding education ($269 m),
(ix) complementary food supplementation ($1359 m),
(x) severe acute malnutrition management ($2563 m).

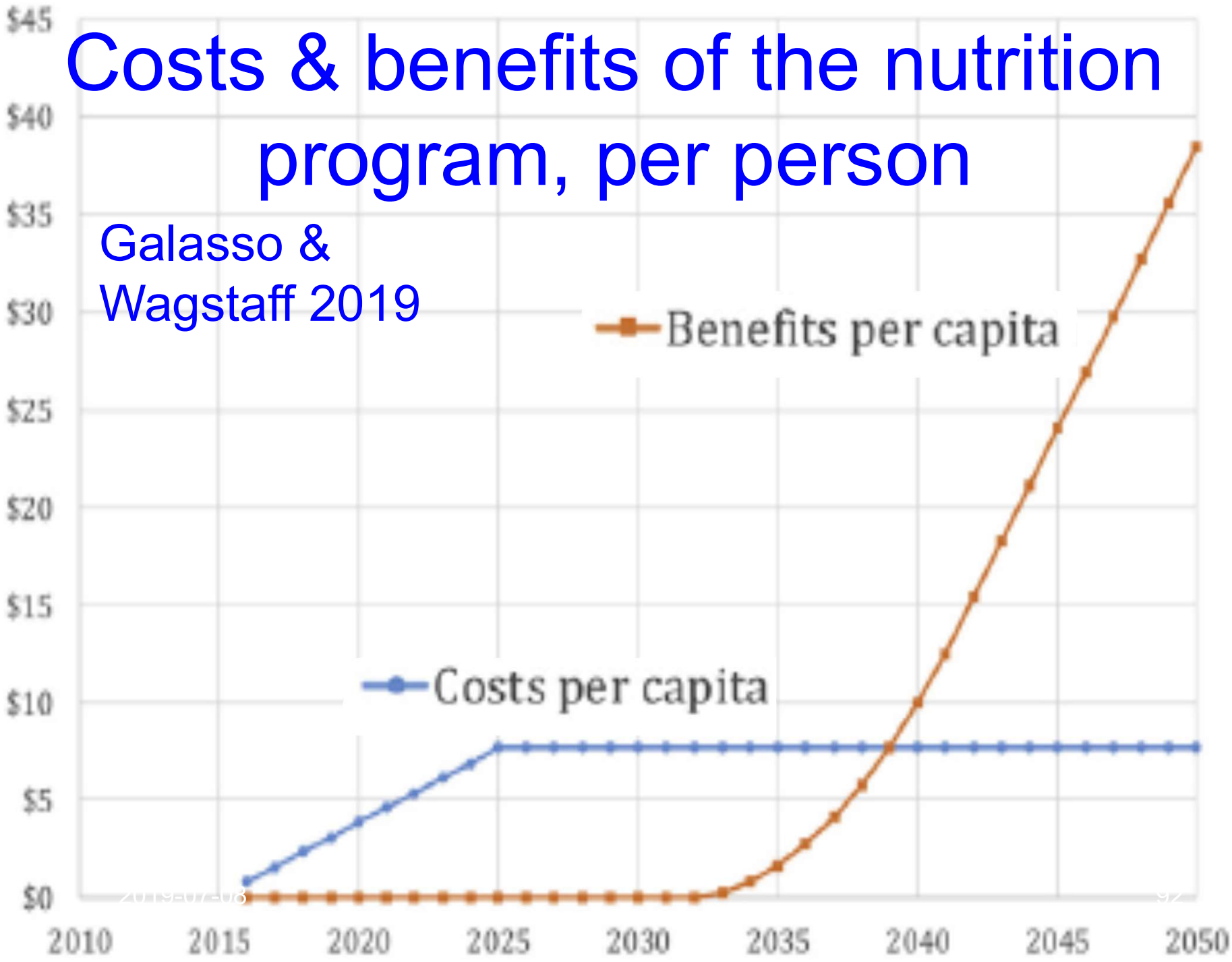
Galasso & Wagstaff 2019 estimate Bhutta et al. 2013's 10 interventions, phased in over 10 years to 90% coverage in 34 developing countries with 90% of world's stunted children, would reduce childhood stunting by 20% & have aggregate cost of $9.559 B PPP 2010 dollars/y.

Reductions in stunting among children <5 & current workers



Costs & benefits of the nutrition program, per person

Galasso & Wagstaff 2019



Benefit-cost ratio

$\Delta y(t), t, = 0, 1, 2, ...$ is the benefit stream (change in income per person due to program of interventions)

$C(t), t = 0, 1, 2, ...$ is the cost stream.

$$Benefit/Cost = \sum_{t=0}^{\infty} \Delta y(t) \,/\, \sum_{t=0}^{\infty} C(t)$$

Galasso & Wagstaff (2019) estimate benefit-cost ratio of 5:1-6:1.

Net present value NPV

Let d be a discount rate (like interest rate).

$C(t), t = 0, 1, 2, \ldots$ is the cost stream.

NPV of cost stream is $\sum_{t=0}^{\infty} \frac{C(t)}{(1+d)^t}$.

$\Delta y(t), t, = 0, 1, 2, \ldots$ is the benefit stream (change in income per person due to program of interventions)

NPV of benefit stream is $\sum_{t=0}^{\infty} \frac{\Delta y(t)}{(1+d)^t}$.

Internal rate of return IRR

The internal rate of return IRR is the value i of the discount rate that makes the NPV of benefits equal the NPV of costs.

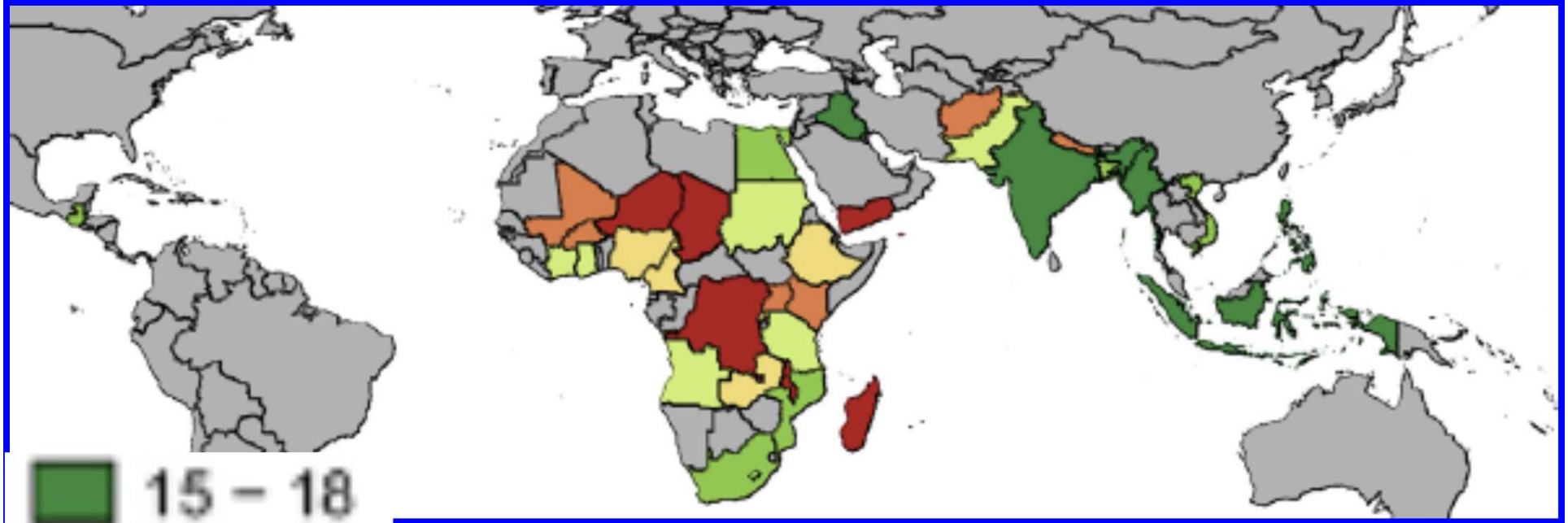
Example: If $C(0) = 1, C(1) = C(2) = \cdots = 0$, $\Delta y(1) = 1.1, \Delta y(t) = 0 \; if \; t \neq 1$, then

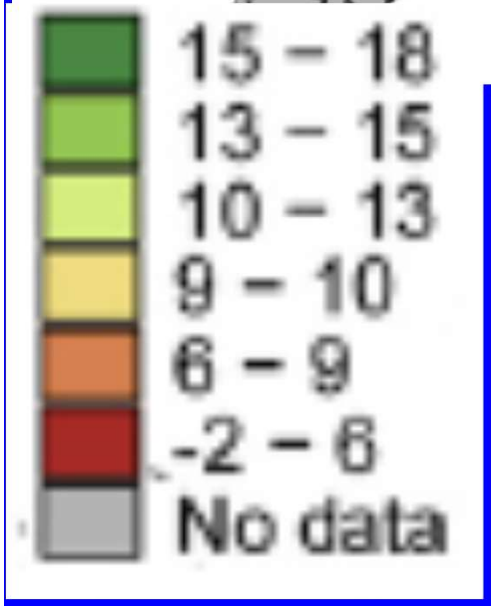
$$\sum_{t=0}^{\infty} \frac{C(t)}{(1+d)^t} = C(0) = \sum_{t=0}^{\infty} \frac{\Delta y(t)}{(1+d)^t} = \frac{\Delta y(1)}{1+0.1} = 1,$$

so the IRR is $i = 0.1$. In general, i satisfies

$$\sum_{t=0}^{\infty} \frac{C(t)}{(1+i)^t} = \sum_{t=0}^{\infty} \frac{\Delta y(t)}{(1+i)^t}.$$

Internal rates of return to nutrition project





Galasso & Wagstaff (2019) estimate an internal rate of return of 12%.

Hunger bonds

Governments should sell bonds to their people & to patient investors to reap returns in the adult labor force of reduced stunting in childhood.

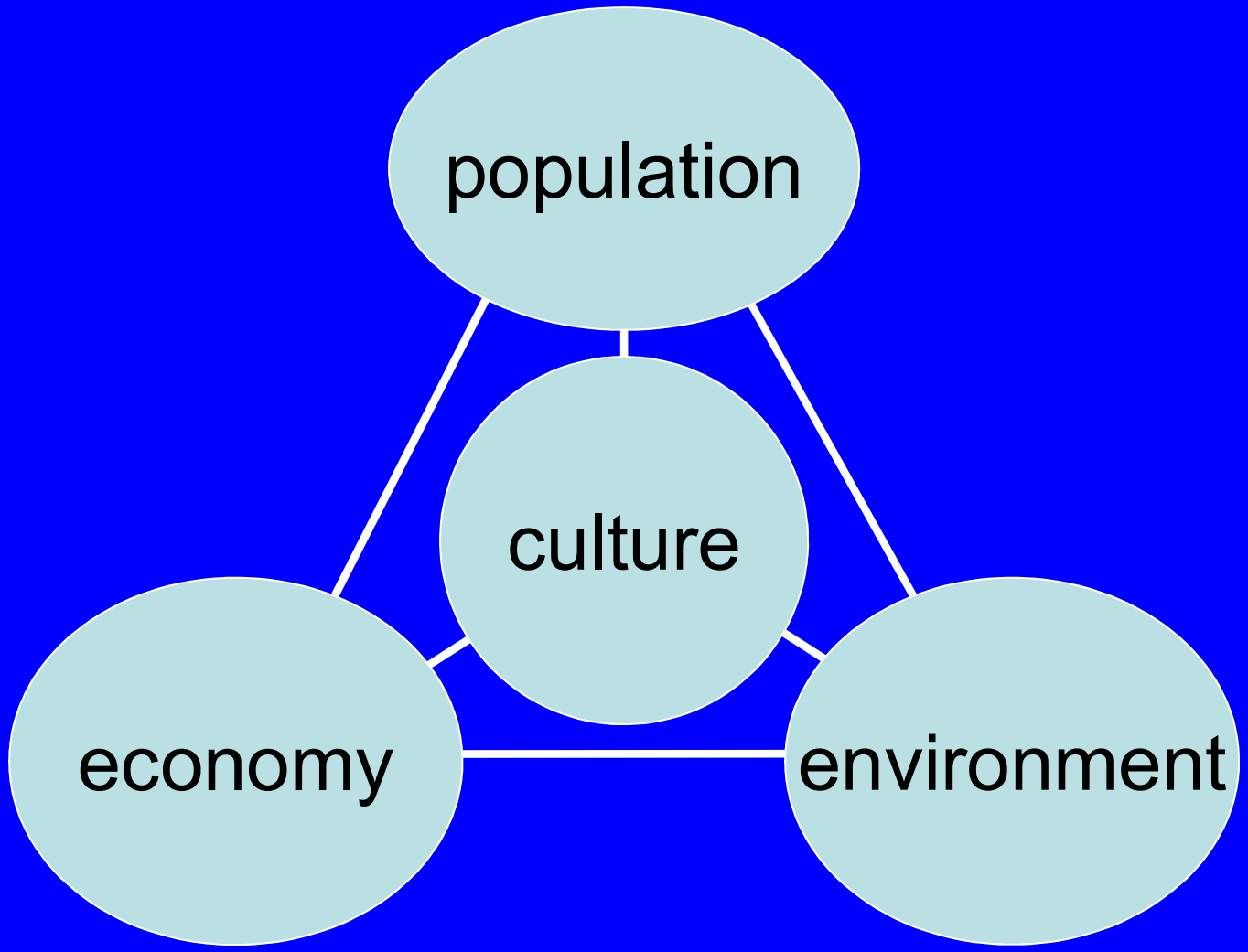
Cost of ending hunger

"Eradicating world hunger sustainably by 2030 will require an estimated additional $267 billion per year on average for investments in rural and urban areas and in social protection, so poor people have access to food and can improve their livelihoods … This would average $160 annually for each person living in extreme poverty over the 15 year period."

FAO, IFAD, WFP, *Achieving Zero Hunger* 2015

J.M.W. Turner (1775-1851): The Slave Ship
1840 Museum of Fine Arts Boston

Population, economics, environment & culture interact.



Thank you! Questions?