Food Systems and Food Security

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Our Plans for Today

- ▶ The context
  - ▶ Some facts
  - ▶ Risk factors
  - ▶ Food systems and MPE
- ▶ Food systems
  - ▶ Complex systems
- ▶ Some questions
  - ▶ Audience participation
- ▶ Three real-world problems
  - ▶ Patrick Canning
    - Economic Research Service, US Dept. of Agriculture
- ▶ Approaches and concepts
  - ▶ Computable General Equilibrium
  - ▶ Planetary boundaries
  - ▶ "Doughnut" economics
- ▶ Some ideas for mathematics

Some Facts

- Out of a *world population* of approximately 7 billion . . .
  - about 2 billion suffer from micronutrient malnutrition ($\approx 30\%$)
  - nearly 800 million suffer from calorie deficiency ($\approx 12\%$)
- Out of approximately 5 billion *adults worldwide* . . .
  - nearly 2 billion are overweight or obese ($\approx 40\%$)
  - 1 in 12 has type 2 diabetes ($\approx 8\%$)
- Out of 667 million *children under age 5 worldwide* . . .
  - 159 million are stunted ($\approx 25\%$)
  - 50 million are wasted ($\approx 7\%$)
  - 41 million are overweight ($\approx 6\%$)
- Out of 129 countries with data . . .
  - 57 have serious levels of both undernutrition and adult overweight (obesity) ($\approx 45\%$)

Source: 2016 Global Nutrition Report, IFPRI

- An estimated 60% of global terrestrial biodiversity loss is related to food production
- Food systems account for an estimated 24% of the global greenhouse gas emissions
- An estimated 33% of soils are moderately to highly degraded due to erosion
- At least 20% of the world's aquifers are overexploited
- Over 80% of the input of minerals (e.g., phosphate) do not reach consumers' plates
- 29% of commercial fish populations are overfished

Source: UNEP Food Systems and Global Resources, 2016

Known Risk Factors for the Early 21st Century

Population growth:
An extra billion people by 2025

Urbanization:
Approximately 55% of population
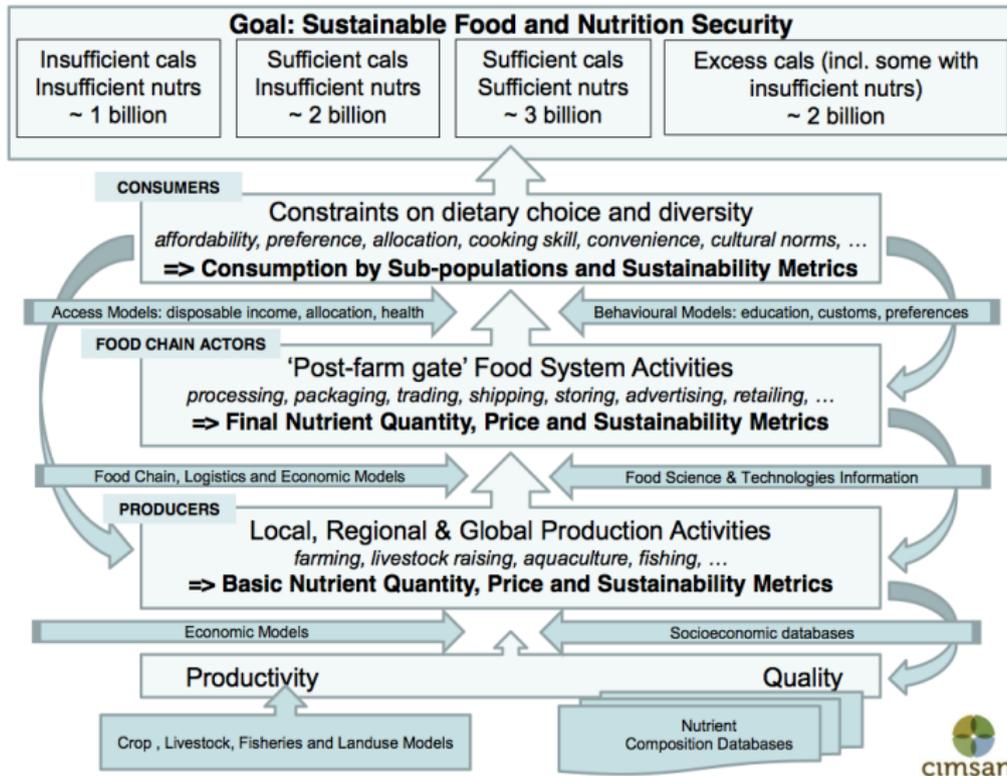live in urban environment by 2025

Climate change:
Today's atmospheric GHGs will
drive changes up to 2030

Food Systems and MPE

- **Impact on the planet**
  - Fundamental dependence on natural resources
  - Land use, soil, water, minerals, biomass, fossil fuels
  - Ecology, environment, biodiversity
- **Impact on society**
  - Economic development, public health, sustainability, globalization, trade
- **Risk and uncertainty**
  - Climate change, natural disasters, extreme events

Food Systems – A Multilayered Network

Goal: Sustainable Food and Nutrition Security

Insufficient cals Insufficient nutrs ~ 1 billion	Sufficient cals Insufficient nutrs ~ 2 billion	Sufficient cals Sufficient nutrs ~ 3 billion	Excess cals (incl. some with insufficient nutrs) ~ 2 billion

CONSUMERS

Constraints on dietary choice and diversity
affordability, preference, allocation, cooking skill, convenience, cultural norms, …
=> Consumption by Sub-populations and Sustainability Metrics

Access Models: disposable income, allocation, health   Behavioural Models: education, customs, preferences

FOOD CHAIN ACTORS

'Post-farm gate' Food System Activities
processing, packaging, trading, shipping, storing, advertising, retailing, …
=> Final Nutrient Quantity, Price and Sustainability Metrics

Food Chain, Logistics and Economic Models   Food Science & Technologies Information

PRODUCERS

Local, Regional & Global Production Activities
farming, livestock raising, aquaculture, fishing, …
=> Basic Nutrient Quantity, Price and Sustainability Metrics

Economic Models   Socioeconomic databases

Productivity   Quality

Crop, Livestock, Fisheries and Landuse Models   Nutrient Composition Databases

cimsans

A Mathematician's Perspective

- Food systems are complex systems
  - Multicomponent: producers, food chain actors, consumers
  - Multiscale: local, regional, global activities
  - Feedback mechanisms: affordability, preferences, cultural norms
- Multilevel approach leads to a hierarchy of models
  - Passing information up and down the hierarchy
  - Agent-based modeling
  - Aggregate (continuum) models
  - Conceptual models
- Modeling challenges at each level
  - Combining agent-based and continuum models
  - Few basic principles (conservation of mass, energy)
  - Phenomenological models (input–output)
  - Lots of data, but what do we need (data by design)
  - Data assimilation, Bayesian approach

- Audience participation

And Now — For the Real World

- Patrick Canning
 - Economic Research Service, US Dept. of Agriculture

Computable General Equilibrium (CGE) Models

- Class of economic models
  - a set of equations describing model variables, assuming optimizing behavior at all levels
  - a detailed database consistent with the model equations, estimated from actual economic data
- Estimate the economic effects of external factors
  - Effects of GHG emissions standards on a national economy
  - Effects of extreme weather events on food systems
  - ...
- Generalization of input–output models (Leontief et al., 1930s)
- First CGE model developed by Leif Johansen, Norway (1960)
- Software packages
  - ▸ GEMPACK
  - ▸ CGE

CGE – General Idea

- Variables
    - Endogenous (economic) variables, $x \in \mathbf{R}^n$
    - Exogenous (external) variables, $y \in \mathbf{R}^m$
- Map $f : (x, y) \mapsto f(x, y) \in \mathbf{R}^n$
- Initial state (x_0, y_0), satisfies $f(x_0, y_0) = 0$
- External perturbation, $y = y_0 + \Delta y$
    - New state $x = x_0 + \Delta x$
    - Impose the condition $f(x, y) = 0$
    - Linear approximation, $f(x, y) \approx (D_x f)_0 \Delta x + (D_y f)_0 \Delta y$
- Impact on endogenous variables,

$$\Delta x = A_0 \, \Delta y, \text{ where } A_0 = -((D_x f)_0)^{-1} (D_y f)_0$$

- Various approximations to A_0

CGEs – Opportunities

- Nonlinear models
  - Multiple equilibrium states
- Transients vs. equilibrium solutions
- Dynamical systems approach
  - Bifurcations
  - Limit cycles
  - Homoclinic orbits, heteroclinic orbits
- Dimension reduction techniques
- Data
  - What data are needed?
 - Data assimilation

A Safe Operating Space for Humanity
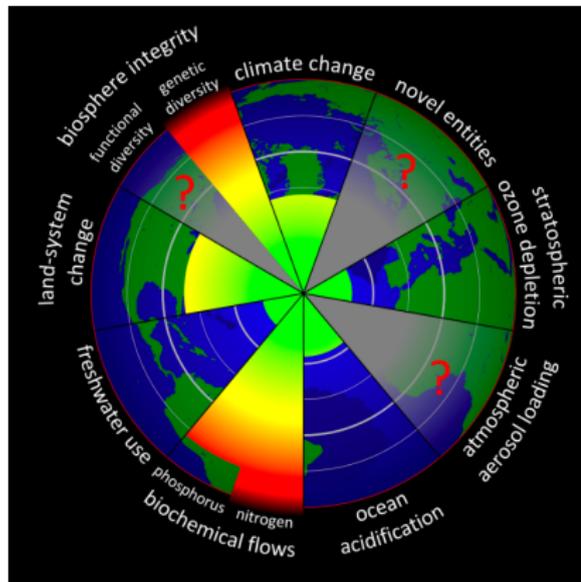
- Planetary boundaries
  - Tipping points
  - Sustainability
  - Resilience
- Conceptual framework
  - Used by UN and EU
  - Ecosystem management
  - Environmental governance indicators

- Johan Rockström (Stockholm Resilience Centre, 1990, 2009)
- Will Steffen (Australian National University, 1990, 2015)

Planetary Boundaries and Their Control Variables

1. Climate change
   - Atmospheric CO_2 [ppm], radiative forcing [W/m^2]
2. Biosphere integrity
   - Extinction rate [species/Myr], genetic diversity
3. Biogeochemical flows
   - Nitrogen, phosphorous [Mt/yr]
4. Ocean acidification
   - Aragonite in sea surface water [ω units]
5. Land system change
   - Land surface converted to crop use [%]
6. Freshwater use
   - Global human consumption [km^3/yr]
7. Ozone depletion
   - Stratospheric ozone concentration [Dobson units]
8. Atmospheric aerosol loading
   - Particulate concentration on regional basis
9. Novel entities, chemical pollution
   - Toxic substances, plastics, radioactive contamination

A Safe and Just Space for Humanity
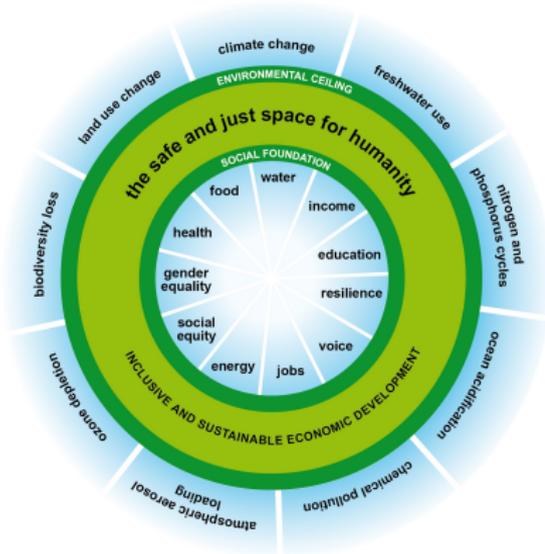
- ► Environmental ceiling
  - ► Tipping points
  - ► Sustainability
  - ► Resilience
- ► Social foundation
  - ► Wellness
  - ► Productivity
  - ► Empowerment

- ► "Doughnut" economics
  - ► Ensure that every person has the resources they need to meet their human rights, while collectively we live within the ecological means of this one planet
- ► Kate Raworth, OXFAM Discussion Paper, 2012

Social Priorities – Rio+20
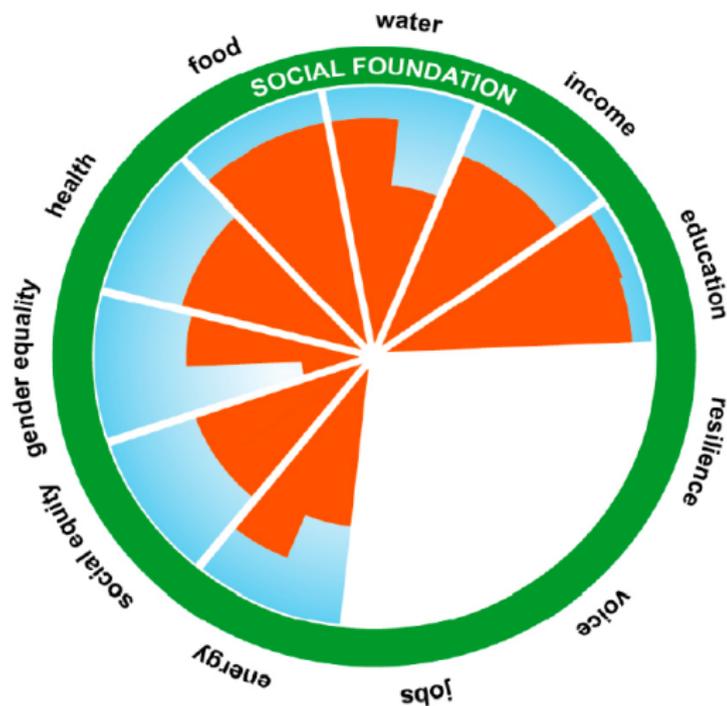
Source: OXFAM, 2012

Social Foundation and Its Control Variables

1. Food security
   - Population undernourished
2. Income
   - Population living on less than $1.25 per day
3. Water and sanitation
   - Population without access to improved water and sanitation
4. Health care
   - Population without access to essential medication
5. Education
   - Children not enrolled in primary school, illiteracy 15-24 yr olds
6. Energy
   - Population lacking access to electricity or cooking facilities
7. Gender equality
   - Employment gap, representation gap in national parliaments
8. Social equity
   - Population living on less than the median income
9. Participation
10. Jobs
11. Resilience

Ideas for Mathematics

▶ Audience participation

THE END