FUTURE CHALLENGES TO FEEDING THE WORLD

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Outline

• Factors affecting food demand
  - Population
  - Income growth
  - Biofuels

• Factors affecting food production
  - Crop yield growth and yield gaps
  - Climate change and crop yields
  - R&D-driven productivity growth

• Where are we headed? Projections with SIMPLE

• Trade-offs in SDGs using SIMPLE-G
Factors Shaping Demand: Population

• In the late 2000s, *The Economist* argued that the population problem was “solving itself”

• Fertility in many middle-income Asian nations had fallen *below replacement levels* – fertility rates in Africa are expected to follow these trends

• At the time, experts projected that by 2050, global population would be at 9 billion persons
A Recent UN Assessment Has Adjusted This Upwards to 9.8 Billion

Population projections remain highly uncertain

Source: World Population Prospects: The 2017 Revision
Much of the Growth Will Come from Africa and Asia

Significant proportional growth in Latin America

Source: World Population Prospects: The 2017 Revision
Alternative Projections of Population Are Based on the IPCC SSP Scenarios

![Graph showing total world population size from 2010 to 2100 with projections for different SSPs: SSP1, SSP2, SSP3, SSP4, SSP5.]

**Table 1**
Matrix with shared socioeconomic pathways definitions for the demographic and human capital component.

<table>
<thead>
<tr>
<th>Country groupings</th>
<th>Fertility</th>
<th>Mortality</th>
<th>Migration</th>
<th>Education</th>
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<tr>
<td>SSP1</td>
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<tr>
<td>HiFert</td>
<td>Low</td>
<td>Low</td>
<td>Medium</td>
<td>High (FT-GET)</td>
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<td>LoFert</td>
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<td>High (FT-GET)</td>
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<td>Rich-OECD</td>
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<td>Rich-OECD</td>
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<td>Low</td>
<td>Low (CER)</td>
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<tr>
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<td>Medium</td>
<td>CER-10%/GET</td>
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<td>CER-10%/GET</td>
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<td>CER/CER-20%</td>
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**Fig. 1.** Trends in total world population size to 2100 according to the five SSPs.

Source: Samir KC, Lutz W. “The human core of the shared socioeconomic pathways: Population scenarios by age, sex and level of education for all countries to 2100.”
Factors Shaping Demand: Income

Source: Southgate, Graham, and Tweeten (2010).
Income Growth Projections Are Also Often Tied to the IPCC SSP Scenarios

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Income Growth Significantly Changes Food Consumption and Composition

2006 (left) versus 2050 (right) due only to income growth (SSP2)

Source: Baldos and Hertel (2014).
Factors Shaping Demand: Biofuels

• Renewable fuel mandates during the early 2000s increased demand for crops as a feedstock for bioenergy production

• Subsidies and government mandates have played an important role in this expansion but are gradually being rolled back

• Future growth is unlikely – unless oil prices rise
Factors Shaping Demand: Biofuels

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EU biofuel consumption (million t.o.e.)

- Ethanol (1st gen)
- Ethanol (2nd gen)
- Biodiesel (waste)
- Biodiesel (1st gen)
- Biodiesel (2nd gen)
- Ethanol (net imports)
- Biodiesel (net imports)
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Factors Shaping Supply: Crop Yields

• FAO estimates over the past 50 years (Bruinsma, 2009):
  - 77% of production growth from yields
  - 9% from increased cropping intensity
  - Just 14% from area expansion
  - Can this be maintained for the next 40 years?

• But yield growth has been slowing
  - Wheat and rice 3-5%/yr in 80’s, but just 1-2%/yr in last decade (Byerlee and Deininger, 2010)
  - Yield growth in 2 dozen breadbasket regions has slowed to less than 0.5%/yr (Fischer, Byerlee and Edmeades, 2009)
Crop Yield Trends for Major Rice, Wheat and Maize-Producing Countries

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- On average, yield might be slowing, but not for all regions
Yield Gaps Remain Large for Key Field Crops, Including in Mexico

Figure 1 | Average yield gaps for maize, wheat and rice. These were measured as a percentage of the attainable yield achieved circa the year 2000. Yield gap in each grid cell is calculated as an area-weighted average across the crops and is displayed on the top 98% of growing area.

Yield Gaps Commonly Result from Nutrient or Irrigation Constraints

Maize

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Closing These Gaps Would Provide a Substantial Boost to Production

Ultimately, Yield Gaps Are Driven by Economic Factors

Robert Herdt’s conclusion from an in-depth IRRI study of rice yield gaps:

- “What is technically possible is more modest than most observers admit; the economics of substantially higher yields is not attractive.”
Economic Factors Influence Production Efficiency in Low-Yield Regions

Darkened green areas are more efficient – serve to “set the frontier”. Circled areas are inefficient, and the primary source of the yield gap is identified.

Factors Shaping Supply: Climate Change

a) Observed global temperature change and modeled responses to stylized anthropogenic emission and forcing pathways

Global warming relative to 1850-1900 (°C)

Estimated anthropogenic warming to date and likely range

Likely range of modeled responses to stylized pathways

- Global CO₂ emissions reach net zero in 2055 while net non-CO₂ radiative forcing is reduced after 2030 (grey in b, c & d)
- Faster CO₂ reductions (blue in b & c) result in a higher probability of limiting warming to 1.5°C
- No reduction of net non-CO₂ radiative forcing (purple in d) results in a lower probability of limiting warming to 1.5°C

Climate Change Will Make Further Growth in Productivity Challenging

“… negative impacts on average yields become likely in the 2030s”

“… median yield impacts from 0 to -2% per decade over the rest of the century”

“… negative impacts of more than 5% are more likely than not after 2050”

Source: Rosenzweig et al (2013), PNAS.
Factors Shaping Supply: Investments in Agriculture R&D

- Public spending in developing countries has responded strongly to increases in food prices during the 2000s
- Private R&D is also up strongly (26%) from 2000-2008

PPP = purchasing power parity.

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Projections from SIMPLE Fall in the Same Range as Other Models

Change in production outcome, 2006-2050

Crop Production (% chg. 2006-50)  Mean = 101.9
Projections from SIMPLE Fall in the Same Range as Other Models

Change in production outcome, 2006-2050

Crop Price (% chg. 2006-50)  Mean = -3.1
Projections from SIMPLE Fall in the Same Range as Other Models

Change in production outcome, 2006-2050

![Graph showing the distribution of change in production outcome from different models. The graph illustrates that SIMPLE's projections fall within the same range as other models, with a mean outcome of 20%.](image-url)
Variability in Model Outcomes Comes from a Small Set of Factors

| Factor                          | Δ% Crop Price | | Δ% Crop Production | | Δ% Crop Land |
|--------------------------------|---------------|-------------------------|-------------------------|-------------------------|
| TFP: Crops                     | 1             | 6                       | 8                       |
| Non-land Supply Elas.          | 2             | 5                       | 6                       |
| Income Per Capita               | 3             | 2                       | 4                       |
| Income Elas.: Proc. Food       | 4             | 3                       | 3                       |
| Population                     | 5             | 4                       | 7                       |
| Income Elas.: Crops            | 6             | 1                       | 5                       |
| Land Supply Elas.              | 7             | 10                      | 1                       |
| Elas. Sub.: Crops              | 8             | 11                      | 2                       |
| TFP: Proc. Food                | 9             | 13                      | 9                       |
| Price Elas.: Crops             | 10            | 15                      | 10                      |
| Biofuels                       | 11            | 12                      | 15                      |
| Price Elas.: Proc. Food        | 12            | 17                      | 16                      |
| Elas. Trans.                   | 13            | 8                       | 11                      |
| Income Elas.: Livestock        | 14            | 14                      | 13                      |
| Elas. Sub.: Livestock          | 15            | 12                      | 14                      |
| TFP: Livestock                 | 16            | 16                      | 17                      |
| Price Elas.: Livestock         | 17            | 17                      | 17                      |
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Recall That Half of the SDGs Relate to Agriculture and the Environment

We should expect to see tradeoffs when pursuing the SDGs
We Can Introduce Policy Interventions with SIMPLE and Observe Their Impact

Eliminate Excess Nitrogen (reductions in MTs)
We Can Introduce Policy Interventions with SIMPLE and Observe Their Impact

Sustainable Water Use
(by reducing irrigated areas)
We Can Introduce Policy Interventions with SIMPLE and Observe Their Impact

Restore Biodiversity
(by reducing irrigated areas)
We Can Introduce Policy Interventions with SIMPLE and Observe Their Impact

Restore Terrestrial Carbon
(by eliminating cropland in critical regions)
Some of These Policies Are Synergistic

- For example
  - Restoring terrestrial carbon also improves biodiversity
  - Targeting conservation of biodiversity would restore terrestrial carbon and also reduce irrigation
    - However, this would increase nitrogen use as compensation
However, these strategies would all increase malnutrition.

Pursuing single SDGs can produce negative impacts.

- Sustainable H2O Use
- Eliminate Excess N
- Restore Terrestrial C
- Restore Biodiversity
- Combined Constraints

Graph showing:
- Caloric Undernutrition Count
- Global Crop Price

Sustainability Interventions

Million Persons vs. Percentage
Conclusions

• How much to produce in the future will still hinge on population and income
  - Population growth expected to slow down
  - Thus, income growth will play a large role in driving food demand

• Productivity growth is key for meeting food needs
  - Closing crop yield gaps can provide short-term gains in productivity
  - In the long run, technological improvements are critical: need to invest in agriculture R&D
Conclusions

- Global-to-local-to-global interconnections result in synergies and trade-offs among SDGs:
  - Restoring biodiversity brings large co-benefits for carbon and groundwater
  - However, area reductions increase intensity of cultivation on remaining croplands
  - Scenarios here highlight vulnerability of poor populations in South Asia, Southeast Asia and Sub-Saharan Africa