Sustainable irrigation in the global food system

Jing Liu, Thomas W. Hertel and Uris L.C. Baldos Purdue University
Richard Lammers, Alexander Prusevich, Danielle Grogan and Steve Frolking
University of New Hampshire
Outline of the talk

• Agricultural irrigation -- a threat to sustainability
• A Hydro-economic model of global irrigation
• Irrigation sustainability in 2050:
  – As affected by irrigation productivity growth
  – In face of climate mitigation
• Consequences for food security and carbon in the presence of:
  – Inter-basin water transfers
  – Integrated commodity markets and trade
• Conclusions
Groundwater irrigation has become increasingly important

- Partly in response to surface water scarcity
- Groundwater is ubiquitous and accessible without large scale government initiatives
- Greater drought resilience, as surface water often not available during drought years
- Reliability in time and space: low transmission and storage losses
- If undertaken in areas with high recharge rates, then it is also sustainable

Source: Burke and Villholth, 2007
But strongest growth has been in arid areas with low recharge rates.
As a result, nonrenewable groundwater abstraction for irrigation is widespread

Wada et al. (WRR, 2012): Estimated nonrenewable groundwater abstraction for irrigation for the year 2000 ($10^6 \text{ m}^3 \text{ yr}^{-1}$).
We focus on sustainable irrigation threshold: Withdrawals less than 20% of available water (Alcamo et al., 2000)

• Irrigation vulnerability index:

\[
\frac{\text{Irrigation Withdrawal}}{\text{Water Available for Irrigation}}
\]

Available water = \((\text{discharge} + \text{storage} + \text{soil-stored water}) - (\text{residential} + \text{industrial} + \text{livestock demands})\)
Outline of the talk

• Agriculture and the threat to global sustainability
• A Hydro-economic model of global irrigation
• Irrigation sustainability in 2050
• Consequences for food security and carbon in the presence of:
  – Productivity growth in irrigated agriculture
  – Climate change mitigation
  – Inter-basin water transfers
  – Integrated commodity markets and trade
• Conclusions
Method: Integrated hydro-economic modelling

Hydro-model:
- Irrigation availability
- Inter-basin transfer

Econ-model:
- Food price
- Malnutrition
- Land use change
- Carbon fluxes
- R&D investment
- Market integration

Sustainability Policies
Method: Integrated hydro-economic modelling

Hydro-model
- Irrigation availability
  - Irrigated area change
  - Inter-basin transfer
    - Irrigation infrastructure
    - Dams & reservoirs
    - Groundwater regulation

Econ-model
- R&D investment
  - Market integration
    - Water use efficiency
    - Food waste reduction
  - Food price
  - Malnutrition
  - Land use change
  - Carbon fluxes
    - Crop yield
    - International trade

Sustainability Policies
Flexible grid size, daily time step, water source/use tracking
Driven by: gridded daily weather, gridded crop & water use maps, reservoirs, IBTs, ...
Water Balance Model
Communicates results to economic model at sub-basin level
SIMPLE-on-a-Grid: Economic Model

Sub-basins are aggregations of grid cells
SIMPLE Validation: Hindcasting 1961-2006

- Exogenous drivers are pop, income, estimated TFP growth, by region and sector

- Productivity growth was more rapid for irrigated croplands: 8.9% over 1961-2006 period

Sources: Baldos and Hertel, ERL (2013); Liu et al., in prep.
Future projections depend critically on the relative rates of Total Factor Productivity (TFP) growth for rainfed and irrigated croplands.

Sources: Alexandratos and Bruinsma, 2012 and authors calculations.
Outline of the talk

• Agriculture and the threat to global sustainability
• A Hydro-economic model of global irrigation
• Irrigation sustainability in 2050
• Consequences for food security and carbon in the presence of:
  – Productivity growth in irrigated agriculture
  – Climate change mitigation
  – Inter-basin water transfers
  – Integrated commodity markets and trade
• Conclusions
Projections to 2050: Unsustainable irrigation (RCP 8.5, equal rates of productivity growth)

Source: author’s calculation.
Irrigation in some regions becomes more sustainable (2006-2050: RCP 8.5, equal TFP)

Source: author's calculation.
Impact on sustainability index of faster productivity growth on irrigated lands

‘Better’ means index value is smaller (more sustainable) with faster irrigation productivity growth
Impact of *climate change mitigation* on sustainability index (RCP 2.6 – 8.5)

‘Better’ means index value is smaller (more sustainable)
Outline of the talk

• Agriculture and the threat to global sustainability
• A Hydro-economic model of global irrigation
• Irrigation sustainability in 2050
• Consequences of irrigation sustainability policies for food security and carbon:
  – BAU
  – In presence of inter-basin water transfers
  – In presence of integrated commodity markets
• Conclusions
Impacts of imposing sustainability in 2050:

- 2006
  - 2050
    - Sustainable 2050
  - 2050 & Water transfer
    - Sustainable 2050
  - 2050 & Integrated Mrkt
    - Sustainable 2050
Imposing sustainable irrigation has adverse impact on food security. Impact on undernourished population in 2050 (1,000’s of people) and on crop prices (% change relative to baseline).

Inter-basin transfers moderate these effects. Integrated markets moderate impact in South Asia.
Imposing sustainable irrigation has adverse impact on food security.
Impact on undernourished population in 2050 (1,000’s of people) and on crop prices (% change relative to baseline).

Inter-basin transfers moderate these effects. 
*Integrated markets exacerbate impacts in SSA.*
Imposing sustainable irrigation has adverse impact on food security. Impact on undernourished population in 2050 (1,000’s of people) and on crop prices (% change relative to baseline).

Inter-basin transfers moderate these effects.
Imposing sustainable Irrigation has mixed effect on cropland cover and terrestrial carbon – (equal TFPs, BAU RCP 8.5)
Map bottom shows net cropland area change under integrated markets

Terrestrial carbon fluxes, by region, due to sustainable irrigation policy
Varied impacts are driven by interaction between cropland change and terrestrial carbon stocks.
Conclusions

• Under BAU scenario, unsustainable irrigation increases in many, but not all, regions.

• Evolving irrigation vulnerability index depends on:
  – Relative rate of productivity growth: irrigation vs. rainfed crops, and
  – Climate change scenario
  – However, effects vary by sub-basin

• Impact of sustainability policy also depends on structure of water and commodity trade:
  – Presence of inter-basin water transfers
  – Extent of commodity market integration
References


