Global Production Networks and Water Depletion

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Internal Applied Lunch Seminar, UPF

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January 29, 2025

Motivation

Globalization: local consumption $\rightarrow$ global environmental consequences

- Why? Complex input-output (IO) linkages across the globe

High attention on CO2 emissions (Copeland and Taylor, 2004, ...)

- Main target of (and issues with) international policy (Nordhaus, 2015)
- Sizeable CO2 footprint of globalization (Shapiro, 2016, 2021)

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This project: focus on **global water** resources.

Motivation – Why Water?

Crucial for domestic consumption and as an input of production

- Agriculture, livestock, textile, steel, brewery, ...

Globalization $\rightarrow$ **virtual water trade** (Hoekstra and Chapagain, 2011)

- Factor trade $\rightarrow$ spatial patterns of economic activity (Davis and Weinstein, 2001; Debaere, 2014)

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Policy concern: upcoming **global water crisis** (OECD's Mazzucato et al., 2023)

- Many (highly populated) water-stressed countries (Carleton et al., 2024)
- Importance of (trade in) agriculture (Carleton et al., 2023)

Research Questions and Outline

1. Does (direct+indirect) water trade $\rightarrow$ pressure on water stressed countries?
2. What is the role of trade policies (e.g., tariffs) vs. domestic distortions?

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This project: **theory + data** = economy's burden in terms of global water stress

1. Theory: network representation of the global economy
2. Data: novel country-sector IO data (1995-2020) + others

Current results: central role of agriculture, non-agric. indirectly important!

- Why? Indirect demand (i.e., inputs) of non-agricultural industries
- $\uparrow$ intermediate demand from water-stress countries

Theory

Theory – The World Economy as a Production Network

$n \in N$ countries, $s \in S$ sectors $\rightarrow i, j \in \Omega = N \times S$ sector–regions. i's output (\$):

$$
\begin{aligned}
x_i &= \overbrace{\sum_n c_{in}}^{\text{final goods}} + \overbrace{\sum_{j \in \Omega} z_{ij}}^{\text{interm. goods}} \\
&= c_i + \sum_{j \in \Omega} a_{ij} x_j, \quad \text{where} \qquad (1) \\
a_{ij} &= z_{ij} / x_j \qquad (2)
\end{aligned}
$$

is j's expenditure share in i goods (as intermediate input)

Theory – The World Economy as a Production Network

Equation (1) is a system of $|\Omega|$ equations; solving for $\mathbf{x}$

$$\begin{aligned} &\mathbf{x} = \mathbf{c} + \mathbf{A}\mathbf{x} \rightarrow \mathbf{x} = \mathbf{L}\mathbf{c}, \quad \text{where} \\ &\mathbf{L} = (\mathbf{I} - \mathbf{A})^{-1} \end{aligned} \tag{3}$$

is the Leontiev inverse that reflects i's importance within supply chains; i.e.

$$\ell_{ij} \in \mathbf{L} \quad \leftrightarrow \quad \ell_{ij} = a_{ij} + \sum_{r=1}^{n} a_{ir} a_{rj} + ... \qquad (+1 \text{ if } i = j) \tag{4}$$

captures all possible (and infinite) paths linking i and j.

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IO data on $\{\mathbf{x}, \mathbf{A}, \mathbf{c}, \mathbf{L}\}$ $\rightarrow$ direct+indirect factor usage in global supply chains

Data

Data: IO + Water Extraction + Water Endowments

GLORIA: MRIO data on $n = 164$ countries $\times 46$ sectors $\rightarrow |\Omega| \sim 6K$

- **Time-varying data** from 1995 to 2020 (raw data >200TB!)

Retrieve/construct (as in Campiglio et al., 2022)

- IO structure of the World economy $\{\mathbf{Z}_t, \mathbf{c}_t\} \rightarrow \{\mathbf{A}_t, \mathbf{L}_t\}$
- $\mathbf{W} = \{W_{it}\} \equiv i$-year-level water extraction

FAO-AQUASTAT: n-level renewable water resources (Kohli and Frenken, 2015)

- Inland waters renewed by water cycle $\rightarrow$ flows, not stocks
- Long-term average (late 20th century) $\equiv \mathcal{W}_n$ (in $10^6 m^3/y$)

Theory + Data: Production Networks and Water Depletion

Production Networks and Water Depletion

1. Does (direct+indirect) water trade $\rightarrow$ pressure on water stressed countries?
   a. Which are the most water stressed countries nowadays?
   b. What is the role of agriculture in the global usage of productive water?
   c. How much (agric.) indirect water use $\rightarrow$ water stressed countries?
   d. How water-intense are other sectors (directly+indirectly)?

2. What is the role of trade policies (e.g., tariffs) vs. domestic distortions?
   - 1.a.-1.d. $\rightarrow$ dimensions to investigate!

Which are the most water stressed countries nowadays?

For 1.a., define water stress $W_n^S = \sum_{i \in \Omega_n} W_{it} / \mathcal{W}_n$, $t \equiv$ average 2016–2020

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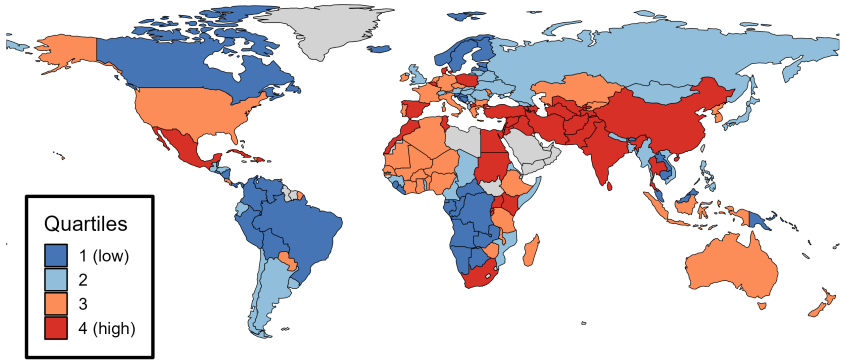

What is the role of agriculture?

For 1.b., agric. productive water use (%)

$$W_t^A = \sum_{i \in \Omega_A} W_{it} / W_t,$$

where $W_t \equiv \sum_i W_{it}$.

What is the role of agriculture?

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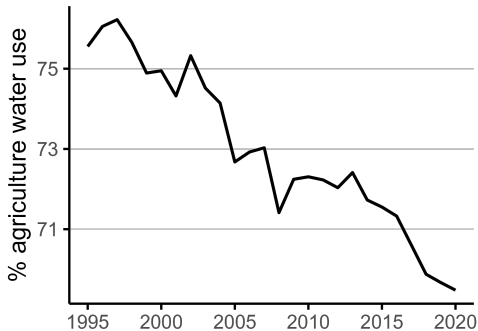
- Agric.: $\sim$ **70% global water use**
- Similar to $\sim$Dubois (2011)

Other i sectors' importance ($\sim$ 30%):

- Geogr. distr. + up/downstreamness



Indirect water use $\rightarrow$ water stressed countries?

For 1.c., direct water intensity: $w_{it} = W_{it}/x_{it}$

Then, i's intermediate water use (%)

$$W^z_{it} = w_{it} \sum_{j \in \Omega} a_{ijt} x_{jt} \quad / \quad \sum_{i \in \Omega} W_{it}$$

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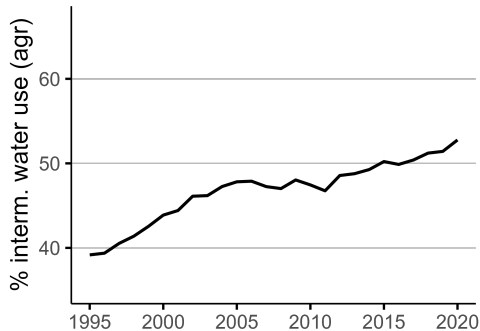
For agric. $(\Omega_A) \sim$ **50% as intermediates**

- Downstream distortions matter!



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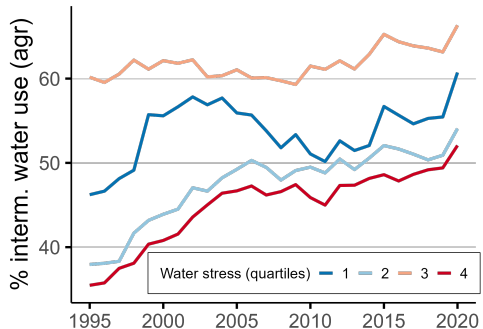
- Water-stressed countries ↑ interm.



How water-intense (directly+indirectly) are other sectors?

For 1.d., ℓ_{ij} in (4) $\rightarrow$ i's total water intensity

$$\omega_i = \sum_{j \in \Omega} \ell_{ji} w_j = \ell_{ii} w_i + \sum_{j \neq i} \ell_{ji} w_j = \ldots$$

$$= w_i + \underbrace{\sum_{j \neq i} \left(a_{ji} + \sum_{r=1}^{n} a_{jr} a_{ri} + \ldots \right) w_j}_{\text{indirect water intensity}}$$

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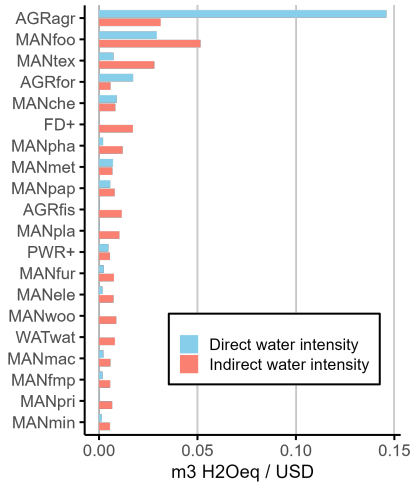
Many indirectly water-intensive industries

- Food processing, textile, chemicals, ...

Related **distortions propagate upstream!**



Takeaways

Productive **water usage**: central role of agriculture and other industries

- IO supply chains $\rightarrow$ global network of water demand (Adao et al., 2017)

Next steps on the role of trade (in intermediates):

- Relationship with trade policy (across all sectors, see Shapiro, 2021)
- Propagation of other distortions (e.g., NTB, subsidies, **market failures**, ...)
- GE experiments with alternative (against optimal) policies

Thank you

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I acknowledge funding from the EU's Horizon Europe research and innovation programme (Marie Sklodowska-Curie grant agreement No 101146979-SPEED) and from the EIEF 2023 grant "International Trade, Globalization, and the Environment".

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