Virtual Water: A Critical Assessment

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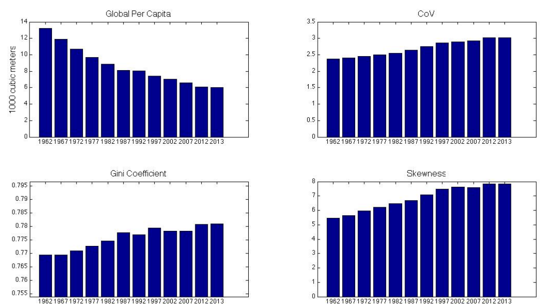
Agenda

- Reminder about the origins of virtual water (VW)
- Possible criticisms and concerns
- Empirical evidence
- Conclusion and future steps

Motivation: Global Water Resources

- Global versus local endowment of fresh water
  - Sufficient per capita renewable fresh water resources at the global level (6000 cubic meters)
  - Spatial mismatch: uneven distribution of water resources
  - Decreasing endowment and increasing unevenness over time
- Popular quote: "many of the wars of the twenty-first century will be about water rather than oil"

Cross Country Renewable Water Endowments Over Time



Raw Data Source: World Bank

Virtual Water (VW)

- A term for quantifying water embedded in goods (Allan 1994)
- The promise: the uneven endowment problem can be mitigated through indirect trade of water:
  - Water scarce countries can offset their shortage by importing water intensive goods
- Largest group of traded VW: cereals, meat, and oil seeds

VW Theory from Economic Theory's Perspective

- Positive: can the trade of water be explained using international trade models?
- Normative: what are welfare effects of observed water trade?
- Policy: what are optimal agriculture trade policies to promote efficient virtual water trade?

Extensive Literature on Evaluating VW

- Theoretical trade models: Ansik (2010), Reimer (2012)
- Global empirical evidence: Delbourg and Diner (2015), ...
- Regional empirical studies: Hakimian (2003), Ma et al (2006), ...

Relevant Trade Theories for (Embedded) Water Trade

- Ricardian: water productivity differences
- Heckscher Ohlin (HO): water endowment differences
- Trade costs and gravity model: lower distance and trade costs
- Krugman/Melitz: economy of scale and monopolistic competition
  - Crops diversity: local climate and soil characteristics

The Heckscher Ohlin Model

- 2∗2∗2 trade model:
  - Countries X and Y with different endowments of water and capital
  - Goods 1 and 2
  - Production factors water (W) and capital (K)
- Country X is capital abundant and country Y is water abundant. i.e., $\frac{K_X}{W_X} > \frac{K_Y}{W_Y}$
- Prediction: water-rich country will export water-intensive goods

The Heckscher Ohlin Model

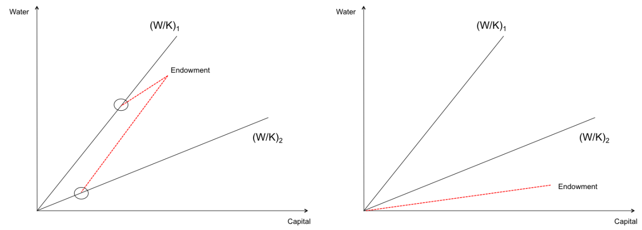


Figure: Cone of Diversification

Critical Review of VW

Vague or Weak Aspects

1. Definition of "water abundant"
   - Empirical behavior: water versus land endowment
2. Possibility of reverse flow of water (from water-poor to water-rich countries)
3. Local versus global water scarcity
4. Green versus blue water
5. A trade model with under-priced factors

Critical Point #1: Definition of Abundance

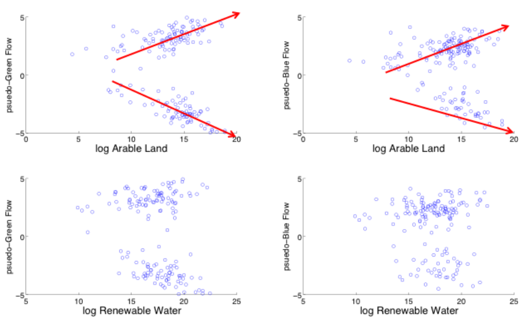
- What is a water abundant country is one which has a high level of:
  - Per-capita water endowment?
  - Ratio of water to other production factors?
  - Endowment of water and land?
  - Absolute (no per-capita) water endowment?
  - Efficiency in water use?
- Arguments and models for each case

Psuedo-Trade

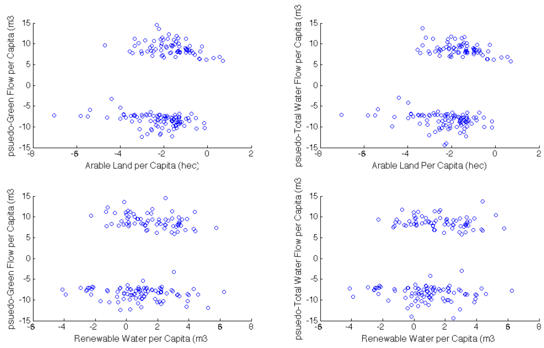
In order to assess the logarithmic relation between traded flows and arable land, a psuedo logarithmic function is introduced:

$$Pseudo - flow = \begin{cases} -log(|Netflow|), & \text{if } NetFlow \leq 0 \\ log(Netflow), & \text{otherwise} \end{cases} \quad (1)$$

Arable Land vs Water Flow



Arable Land vs Water Flow



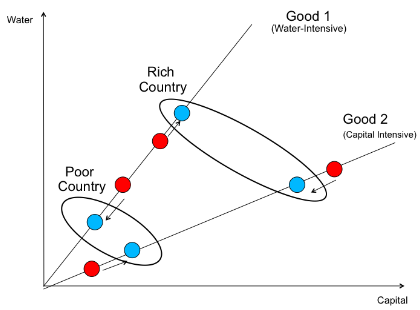
Critical Point #2: Possibility of a Reverse Flow

- Net flow of water trade: from arid to water-abundant regions!
- Pressure on water resources of water-poor country
- Empirical evidence/observations
  - North-South China, East India, ...
  - Water-poor countries: e.g., Mongolia, Afghanistan
  - Water-abundant countries: Japan, UK.

HO Model of Reverse Trade

- Two countries:
  - Country A: low level of water, lower level of capital
  - Country B: high level of water, higher level of capital
- Autarky:
  - Country A: consumes water-intensive goods
  - Country B: consumes capital-intensive goods
- Trade:
  - Both countries consume the same type of goods; however, B consumes a scaled bundle
  - A: net exporter of water, B: net importer of water

Consumption Bundles Before and After Trade



Critical Point #3: Local and Global Scarcity of Water

Using Virtual Water to Inform Public

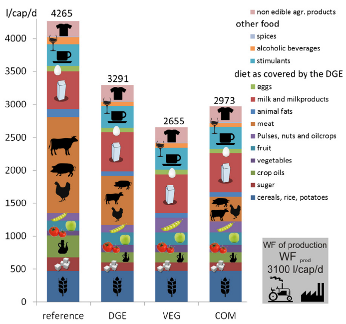
Virtual water content for selected products
[m^3/ton]
(Zimmer D., and D. Renault, 2003)

Beef	13 500
Pork	4 600
Poultry	4 100
Soybean	2 750
Eggs	2 700
Rice	1 400
Wheat	1 160
Milk	790

Virtual water content of diets
[m3/person/day]
(D. Renault, W.W. Wallender, 2000)

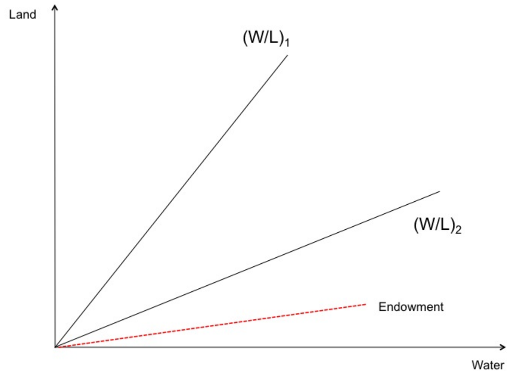
Diet 0 (reference USA)	5.4
Diet 1 25% reduction animal product	4.6
Diet 2 poultry replaces 50% beef	4.8
Diet 3 vegetal products replaces 50% red meat	4.4
Diet 4 50% reduction of animal products	3.4
Diet 5 vegetarian	2.6
Diet 6 Survival	1.0

Using Virtual Water to Inform Public



Source: Vanham et al (2013)

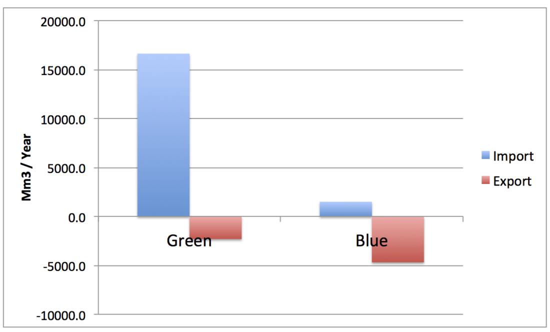
Producing Outside of the Cone: Land Scarce Countries



Critical Point #4: Source of Water

- Depletion of underground water resources is a chief concern: blue water
- Green water use is mainly limited to agriculture
- Environmental effects of green water footprint less severe (also not received an attention in the literature)
- Asymmetric problem: flow (green) versus stock (blue)
  - One side solving an optima resource extraction problem!

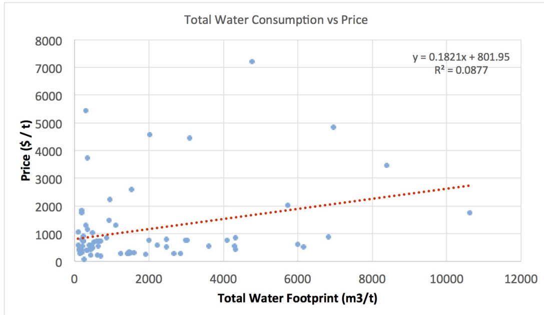
Example: Iran's Import and Export of Virtual Water



Critical Point #5: Water Price

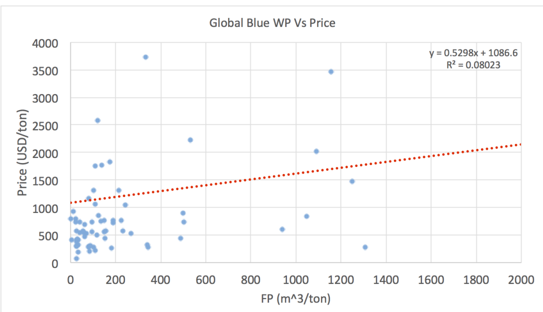
- HO model assumes a market clearing constraint
- Local scarcity determines the optimal bundles of production
- Water price is zero or near-zero in many regions
- Signal of scarcity?

Total Water Content and Crop Prices



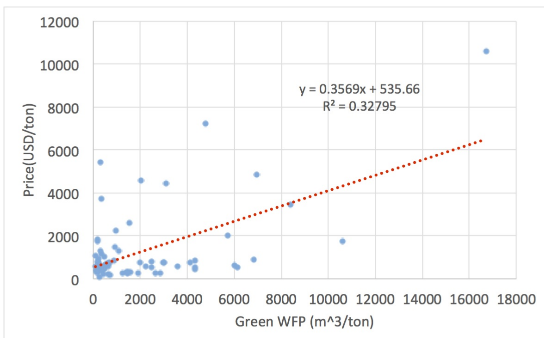
Data Source: IMF and FAO

Blue Water Content and Crop Prices



Data Source: IMF and FAO

Green Water Content and Crop Prices



Data Source: IMF and FAO

Conclusion

- The potential of virtual water trade to reduce water endowment can be limited by land (and possibly capital and labor) endowments.
- Definition of water abundance: "total water endowment", "relative water endowment", and "per capital water endowment"
- The contrast between local and global scarcity of virtual water
- Better measures to compare blue/green water content to quantify the pattern of trade and the pressure on water resources of different countries.