Virtual Water Imports: Using Agricultural Trade to Cope with Water Scarcity

Miguel Cárdenas Rodriguez[1] and Alban Thomas[2]

[1]OECD, Paris
[2]Toulouse School of Economics (LERNA, INRA)

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Introduction

Policies to narrow the gap between water availability and demand:

- Demand-side management policies
  - *Command-and-control* instruments
    - non-tradeable quotas
    - Technological standards
    - Rationing and restrictions of use
  - Market-based instruments
    - Taxes
    - Tarrifs (level and type)
    - Investment subsidies
    - Tradeable permits
  - Other policies
    - Voluntary agreements
    - Implementation of informal markets
    - Awareness and information campaigns

Expected impact of demand-side policies: price and tax

Table: Estimation of price elasticity of residential water demand

Article	Country	Year	Elasticity
Nauges Thomas	France	2000	-0.21
Nauges Thomas	France	2003	-0.26
Garcia Reynaud	France	2004	-0.25
Martinez-Espiñeira Nauges	Spain	2004	-0.10
Garcia-Valinas	Spain	2005	-0.49
Arbues Villanua	Spain	2006	-0.08
Reynaud Thomas	France	2006	[-0.05 ; -0.13]
Bithas Stoforos	Greece	2006	-0.10
Mazzanti Montini	Italy	2006	[0.99 ; -1.33]
Musolesi	Italy	2007	-0.27
Martinez-Espiñeira	Spain	2007	[-0.07; -0.16]
Statzu Strazzera	Italy	2007	-0.22
Schleich Hillenbrand	Germany	2007	[-0.23; -0.59]
Arbues Villanua	Spain	2010	[-0.26 ; -0.57]

Other demand-side management policies

- Rationing and restrictions of use
- Subsidies for HH appliances and new technologies
- Awareness and information campaigns

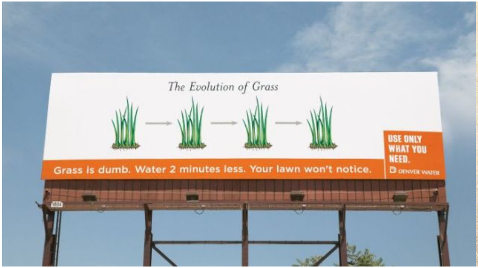


Table: Effect of non-price policies on residential water demand

Author	Country	Policy	Change in demand (%)
Ruis et al. (2008)	US	Rationing	-8.6
Kenney et al. (2004)	US	Restriction	[-18.0 ; -56.0]
	(Colorado)	Information	[-4.0 ; -12.0]
Kenney et al. (2008)	US	Restriction	-12.12
Renwick Green (2000)	US	Restriction	-29.0
	(California)	Rationing	-21.0
		Subsidies	-9.0
		Information	-8.0
Grafton Kompas (2007)	Australia (Sydney)	Restriction	-10.0
Bartczak et al. (2009)	Poland	Meters	-20.0

or

- Supply-side policies
  - Coping with seasonal variability (reservoirs, dams, ...)
  - Increase water available volumes, leaving consumption more or less unchanged
    - Production of fresh water (sea water desalinization)
    - Recycling wastewater ("gray water")
    - Restoring groundwater resources by injection

or finally

- Indirectly complement fresh water volumes through imported products

Which policy is best?

- Cost-Benefit Analysis
- Cost-Efficiency Analysis

Table: Desalinization plant capacity, 2009

Country	Capacity (m^3/day)	Capacity per head (m^3/head/day)
Saudi Arabia	7 410 460	0.28
UAE	5 730 000	1.07
Spain	2 500 000	0.053
Qatar	1 197 150	0.613
Libya	1 000 000	0.178
Israël	800 000	0.105
Bahrein	518 600	0.415
Egypt	431 870	0.005
Oman	377 480	0.122
Australia (2009)	294 000	0.013
Australia (expected 2013)	2 200 000	0.099
Jordan	239 530	0.036
Algeria	200 000	0.005
Singapore	136 000	0.025
Malta	93 000	0.227

Cost-efficiency analysis: example of Algeria

- Emergency programme of seawater desalinization adopted in 2002
- Objectif towards 2030: 2.2 million m^3/day
- Cost-efficiency analysis: comparison of two strategies
  - supply-side management: seawater desalinization (the current plan)
  - demand-side management: promote a more efficient irrigation
  - Duration: 20 years (discount rate 8 %)

Akli, S. and S. Bedrani, Cahiers du CREAD, 96, 2011.

Desalinization	Irrigation
• Eight single-block stations Inverse osmosis • Production 4.58 Mm3/year • Return 60 % • Cost: 68.34 DA/m^3 (0.66 euro/m^3)	• Irrigation (fruit trees), West Mitidja • Yield drip irrigation: 35 % • Same reduction objective Area considered 1852 ha • Saving: 8.59 DA/m^3 (0.08 euro/m^3)

Virtual Water: Definition and Concepts

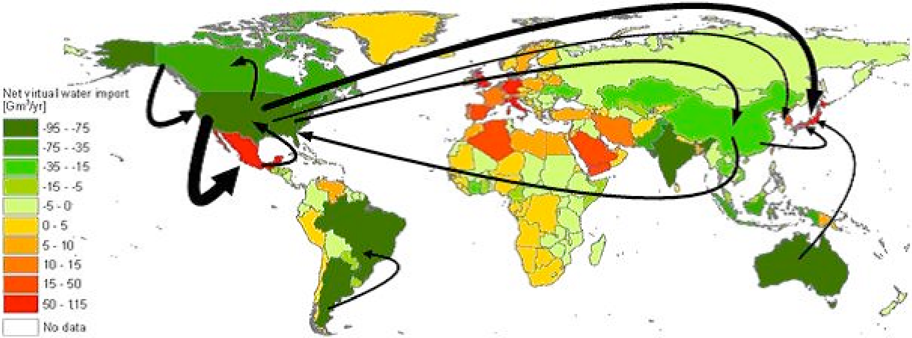
Variable	Definition
Virtual water	Water used for the production of a good or service, not visible in the final product
Virtual water content of a product	Volume of fresh water consumed or polluted for producing a product
Water Footprint	Multi dimensional indicator of freshwater use (both direct and indirect) by a consumer or producer
Blue water	Fresh surface or groundwater
Green water	Precipitation on land that does not run off or recharge the groundwater but is stored in the soil or temporarily stays on top of the soil or vegetation
Grey water	Volume of polluted water flow, aquifers and rivers

Table: Hidden water use (virtual water) in domestic goods

Commodity	Water consumed (litre)
1 litre of beer	7
1 litre of gasoline	10
1 cola	70
A single bath	200
1 kg of paper	320
1 kg of bread	1,000
1 kg of potatoes	1,000
Television set	1,000
1 kg of meat	4,000 to 10,000
One pair of jeans	8,000

Source: UNEP (2004).

Virtual water balance per country related to trade in agricultural and industrial products, 1996-2005. Net exporters are in green, net importers in red.



Source: Mekonnen and Hoekstra (2011).

The case of crops

- Focus on crops because of agriculture a major water user

$$\text{Crop Virtual Water content } (m^3/t) = \frac{\text{Crop Water Requirement}(m^3/ha)}{\text{Crop Yield}(t/ha)}$$

Table: Examples of Water Footprint in m^3/ton

Country	Wheat			Maize		
	Green	Blue	Grey	Green	Blue	Grey
France	581.24	1.33	5.50	425.92	92.21	156.44
Mexico	332.81	558.29	184.71	1851.85	61.76	356.95
Global average	1277.21	342.46	207.42	947.20	81.23	193.93

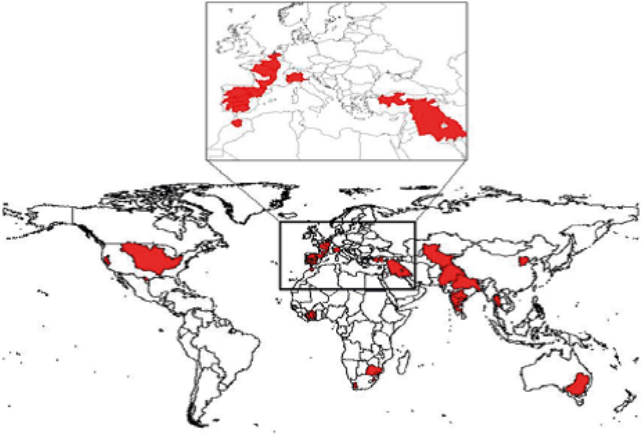
Table: International virtual-water flows per product category (billion m^3/year)

Product	Green	Blue	Grey	Total	% of global flow
Seed Cotton	327.31	166.99	74.52	568.83	24.5
Soybean	194.63	5.60	2.66	202.90	8.7
Wheat	174.87	7.85	17.90	200.62	8.6

Table: Water imports related to trade in crops, per country (billion m^3/year)

Country	NVWI
Japan	90.34
Germany	53.93
Mexico	50.28
India	-81.25
Argentina	-88.12
US	-93.13

Hotspots of blue water footprints for products exported to France.



Source: WWF (2012).

Table: Hotspots of the French blue water footprint for agricultural products

Region	% Blue Water Footprint	Product(s)
Aral Sea (Uzbekistan)	6.38	Cotton
Garonne (France)	5.44	Maize, soybean
Escaut (France)	4.46	Maize, potato
Loire (France)	4.43	Maize
Indus (Pakistan)	3.85	Cotton, rice, sugarcane
Guadalquivir (Spain-Portugal)	2.98	Cotton, sunflower, rice, sugarbeet
Seine (France)	2.23	Maize, potato, sugarbeet
Gange (India)	2.19	Rice, sugarcane
Guadiana (Spain-Portugal)	1.79	Grape, sunflower, citrus
Tiger & Euphrate (Turkey, Syria, Iraq)	1.62	Cotton, rice
Po (Italy)	1.59	Rice, animal products
Ebro (Spain)	1.39	Maize
Sebou (Morocco)	1.39	Sugarbeet
Douro (Spain-Portugal)	1.29	Maize, sugarbeet
Tejo (Spain-Portugal)	1.02	grape, maize, animal products
Mississippi (US)	0.60	Maize, soybean, rice, cotton
Krishna (India)	0.45	Rice, sugarcane
Godavari (India)	0.31	Rice, sugarcane
Kizilirmak (Turkey)	0.27	Sugarbeet
Chao Phraya (Thailand)	0.26	Rice, sugarcane
Sakarya (Turkey)	0.25	Sugarbeet
Bandama (Cote d'Ivoire)	0.21	Sugarcane, animal products
Cauvery (India)	0.19	Rice, sugarcane
Yongding He (China)	0.12	Cotton, soybean
Limpopo (SOuth Africa)	0.11	Sugarcane, cotton
Sacramento (US)	0.10	Rice
San Joaquin (US)	0.10	Cotton, Maize

Literature

- Almost no theoretical analysis
- focus on computing virtual water coefficients and its relevance in international water policy making
- Use of international trade theories (Ricardian Model of comparative advantages, Hecksher-Ohlin): Tomini (2009), Zimmer and Renault (2003)
- Hoekstra and Hung (2002), Mekonnen and Hoekstra (2010), Chapagain and Hoekstra (2006), Ocki and Kanae (2003), Wichelns (2006): study on virtual water content for major crops, livestock and industrial products.
- Since 2008, Water Footprint Network website: update databases
- International water policy: Warner (2002) and Allan (2003) on water wars and stronger interdependency to eliminate conflicts

- The literature on virtual water points out to globalization of water resources and advocates for trade liberalization in order to manage water resources globally and enhance food security
- Yang et al (2003): below threshold of 1500 m^3/head/year, the demand for cereal import from Asia and Afria increases exponentially
- Hoekstra and Hung (2002): no apparent relationship between water resources and net imports of virtual water
- But this study fails to acknowledge the importance of determinants of demand for agricultural virtual water: agricultural land, irrigation systems, income, diet habits and availability of various types of water.

Water and Land Heterogeneity across Regions

Table: Water resources (m^3 per capita) and Agricultural Land (m^2 per capita)

Country	Surface water	Ground water	Precipitation	Agricultural land
Malta	1.22	122.23	438.08	220.04
Bahrain	4.32	120.98	67.19	84.35
UAE	27.75	22.19	1206.35	1076.19
Suriname	23,9151.9	156,820.9	748,623.9	1435.35
Guyana	321,304.2	137,320.9	684,071.3	22,346.28
Iceland	532,792.4	77,030.23	641,276.6	73,729.38

Table: Water and Land by Region

Region	Surface water	Ground water	Precipitation	Agricultural land
	(billion m^3/year)			(m^2 per capita)
East Asia & Pacific	26.99	6.42	60.05	29.34
Europe & Central Asia	21.20	3.42	28.54	11.51
Latin America & Caribbean	46.95	17.19	80.13	8.72
MENA	4.65	0.19	3.40	8.52
North America	48.74	7.91	92.84	16.94
South Asia	19.24	1.97	19.10	3.33
Sub-Saharan Africa	15.50	3.80	41.71	22.31

Table: Water and Land by Income Level

Income class	Surface water	Ground water	Precipitation	Agricultural land
	(billion m^3/year)			(m^2 per capita)
High income: OECD	30.66	4.86	48.39	14.24
High income: non-OECD	2.05	0.4046	8.21	5.45
Low income	10.09	2.36	26.00	14.45
Lower middle income	31.53	8.54	56.77	17.87
Upper middle income	22.70	7.68	50.90	18.96

An interesting concept: Net Virtual Water Imports

Table: Net Virtual Water Imports from agricultural products, by region and income class (billion m^3/year)

Region	NVWI
East Asia & Pacific	12.12
Europe & Central Asia	236.80
Latin America & Caribbean	-106.35
Middle East & North Africa	93.00
North America	-131.98
South Asia	-109.70

Income	NVWI
High income: OECD	225.26
High income: non-OECD	50.42
Low income	-6.87
Lower middle income	-205.97
Upper middle income	-95.53

Empirical Application

- Objective: Extend usual estimation of NVWI by controlling for nature of water resources, agricultural land, and import prices
- Restriction to agricultural products (crops)
- Country-level data, period 1990-2009
  - FAOSTAT
  - Aquastat
  - World Bank
  - 150 countries observed over the period
- Assumptions to be tested:
  - Substitutability between surface, groundwater, and rainfall
  - Significance of GDP and import price in virtual water imports
  - Presence of country-specific fixed effects
  - Presence of period-specific fixed effects

Estimated equation

$$NVWI_{it} = \beta_0 + \beta_1 GDP_{it} + \beta_2 \log P_{it} + \sum_{j=1}^{4} \gamma_j X_{j,it} + \sum_{k=1}^{4} \sum_{l=1}^{4} \gamma_{kl} X_{k,it} X_{l,it} + \alpha_i + \varepsilon_{it}$$

where

- $NVWI_{it}$: Net Virtual Water Imports of country i for year t
- GDP_{it}: Gross Domestic Product ($\times$ USD 2000)
- $\log P_{it}$: Törnqvist price index of imports

$$\log P_{it} = \frac{1}{2} \sum_{i=1}^{n} \left(\frac{P_{i0} Q_{i0}}{P_0 Q_0} + \frac{P_{it} Q_{it}}{P_t Q_t} \right) \log \left(\frac{P_{it}}{P_{i0}} \right)$$

- X_{it} =(surface water, ground water, rainfall, agr. land)

- Surface Water: the sum of internal renewable water resources and external actual renewable water resources. It corresponds to the maximum theoretical yearly amount of water actually available for a country at a given moment. Measured in cubic meters per capita per period. Defined by the AQUASTAT database from FAO

- Groundwater: the sum of the internal renewable groundwater resources and the total external actual renewable groundwater resources. Measured in cubic meters per capita per period

- Precipitation: the long-term average, over space and time, of annual endogenous precipitation in volume produced in the country. Measured in cubic meters per capita per period

- Agricultural Land: the sum of areas under arable land, permanent crops and permanent meadows and pastures. Measured in squared meters per capita per period

Countries classified in 7 geographical regions according to the World Bank:

- North America
- Latin America & Caribbean
- Europe & Central Asia
- Middle East & North Africa
- Sub-Saharan Africa
- East Asia & Pacific
- South Asia

Divided in 5 income levels according to the World Bank classification

- High income: OECD
- High income: non OECD
- Upper middle income
- Lower middle income
- Low income

Specification Tests

- Hausman test for fixed vs. random effects

$$\chi^2(4) = 6.64 \qquad (p\text{-value } 0.0562)$$

- Fisher test for time effects

$$F(3, 305) = 1.44 \qquad (p\text{-value } 0.2309)$$

- Wald test for group heteroskedasticity

$$\chi^2(134) = 3.5e + 32 \qquad (p\text{-value } 0.0000)$$

Estimation Results

Table: Robust Fixed-Effects Regression for All Countries

Variable	Coefficient	Std. Err.
gdp_pc	0.005015685	0.013846400
lnP	-51.164826303	244.407774354
surf_pc	0.058325531	0.046616696
ground_pc	-0.203277923	0.163973450
prec_pc	0.012322281	0.024471256
agrland_pc	-0.005425653	0.012702709
c.surf_pc#c.surf_pc	7.970000000*	3.780000000
c.surf_pc#c.ground_pc	-7.933000000*	3.576000000
c.surf_pc#c.prec_pc	-6.750000000**	2.540000000
c.surf_pc#c.agrland_pc	6.171000000*	2.481000000
c.ground_pc#c.ground_pc	-9.114000000	5.510000000
c.ground_pc#c.prec_pc	8.584000000**	3.142000000
c.ground_pc#c.agrland_pc	-0.000029144**	0.000010763
c.prec_pc#c.prec_pc	-3.170000000*	1.250000000
c.prec_pc#c.agrland_pc	1.000000000	9.100000000
c.agrland_pc#c.agrland_pc	-2.600000000	2.000000000
Intercept	-1472.558986536*	681.627311624
N	458	
R^2	0.271984194	

Significance levels : † : 10% ∗ : 5% ∗∗ : 1%

Table: Robust Fixed-Effects Regression for Latin America & Caribbean

Variable	Coefficient	Std. Err.
gdp_pc	-0.070058505	0.163144968
lnP	-1000.906641466**	339.844141633
surf_pc	-0.507109359	0.408194012
ground_pc	-1.729296243	1.012930580
prec_pc	0.614255902*	0.257992463
agrland_pc	-0.605083427**	0.190127984
c.surf_pc#c.surf_pc	7.398000000	7.536000000
c.surf_pc#c.ground_pc	0.000044095	0.000030523
c.surf_pc#c.prec_pc	-0.000017451	0.000015189
c.surf_pc#c.agrland_pc	0.000034870**	0.000010159
c.ground_pc#c.ground_pc	0.000132976†	0.000075659
c.ground_pc#c.prec_pc	-0.000069367†	0.000038794
c.ground_pc#c.agrland_pc	0.000072744†	0.000041829
c.prec_pc#c.prec_pc	0.000011036	6.905000000
c.prec_pc#c.agrland_pc	-0.000033078*	0.000012264
c.agrland_pc#c.agrland_pc	0.000019951**	6.746000000
Intercept	-5557.555742182	10740.325134442
N	87	
R^2	0.735033569	
$F_{(15,23)}$	3028.644924698	

Significance levels : † : 10% * : 5% ** : 1%

Table: Robust Fixed-Effects Regression for Europe & Central Asia

Variable	Coefficient	Std. Err.
gdp_pc	-0.007514859	0.014929366
lnP	859.728115186†	426.363309580
surf_pc	-0.131477143	0.274876249
ground_pc	1.410378831	0.924347923
prec_pc	-0.159497620	0.215527693
agrland_pc	-0.048209354	0.047112588
c.surf_pc#c.surf_pc	-0.000065140†	0.000035371
c.surf_pc#c.ground_pc	-0.000136352	0.000122700
c.surf_pc#c.prec_pc	0.000109560*	0.000052102
c.surf_pc#c.agrland_pc	-9.791000000	8.442000000
c.ground_pc#c.ground_pc	0.000334027**	0.000119989
c.ground_pc#c.prec_pc	-6.485000000	0.000081415
c.ground_pc#c.agrland_pc	-9.854000000	0.000042610
c.prec_pc#c.prec_pc	-0.000036351†	0.000019283
c.prec_pc#c.agrland_pc	8.655000000	8.355000000
c.agrland_pc#c.agrland_pc	4.400000000	1.263000000
Intercept	3097.865998342**	1044.359981492
N	143	
R^2	0.299298936	

Significance levels : † : 10% ∗ : 5% ∗∗ : 1%

Elasticity of Net Virtual Water Imports

Table: Water and Land by Region

	Elasticity of NVWI wrt.					
Region	GDP	P	surface water	ground water	rainfall	agr. land
All	-0.0085	0.0710	-0.6718	0.6387	0.0123	0.0050
Latin America	0.1186	1.3894	-0.0125	0.4779	0.0807	-0.0979
Europe & Central Asia	0.0127	-1.1934	-1.4187	-0.0661	6.9633	-0.2758
MENA	0.0288	-0.6227	-5.6888	6.3683	-17.1350	9.0868
Sub Saharan Africa	-0.1348	0.2655	0.0359	-0.0240	0.0769	-0.0005
Eastern Asia & Pacific	0.0119	-0.2997	-5.4194	2.8106	0.6096	2.3292

Result Summary

- Model with all countries:
  - NVWI is concave in surface water and convex in rainfall
  - NVWI decreases with ground water and agricultural land (*expected*)
- Latin America & Caribbean
  - NVWI decreases with import prices and rainfall (*expected*)
  - NVWI increases with surface water (*unexpected*)
  - NVWI is convex in groundwater and agricultural land
- Europe & Central Asia
  - Agricultural land has no effect
  - Groundwater if convex (increasing)
  - Surface water and precipitation are concave (decreasing)
- Sub-Saharan Africa
  - GDP is positive (only significant for this region)
  - Groundwater, rainfall and agricultural land are convex (increasing)

Result Summary

- Model with the best results: Lower-middle income countries
  - NVWI is increasing in GDP
  - NVWI is decreasing in import price index
  - NVWI is decreasing and convex in surface and groundwater
  - NVWI is increasing in precipitation (*unexpected*)
- Severe data limitations (from Aquastat), unbalanced panel
- Fixed-effects estimators not efficient, need for more data points

Conclusion

- Attempt to address the issue of the origin of water resources, and trade prices in virtual water studies
- Preliminary results, poorly satisfactory due to data limitations
- Other control variables in NVWI to consider: energy and fertiliser consumption, irrigation efficiency
- Virtual water flows also depend on water efficiency and productivity gaps across trade partners
- Need to account for productivity growth and technological change

Thank you for your attention

thomas@toulouse.inra.fr