The unimportance of “virtual water" for environmental policy

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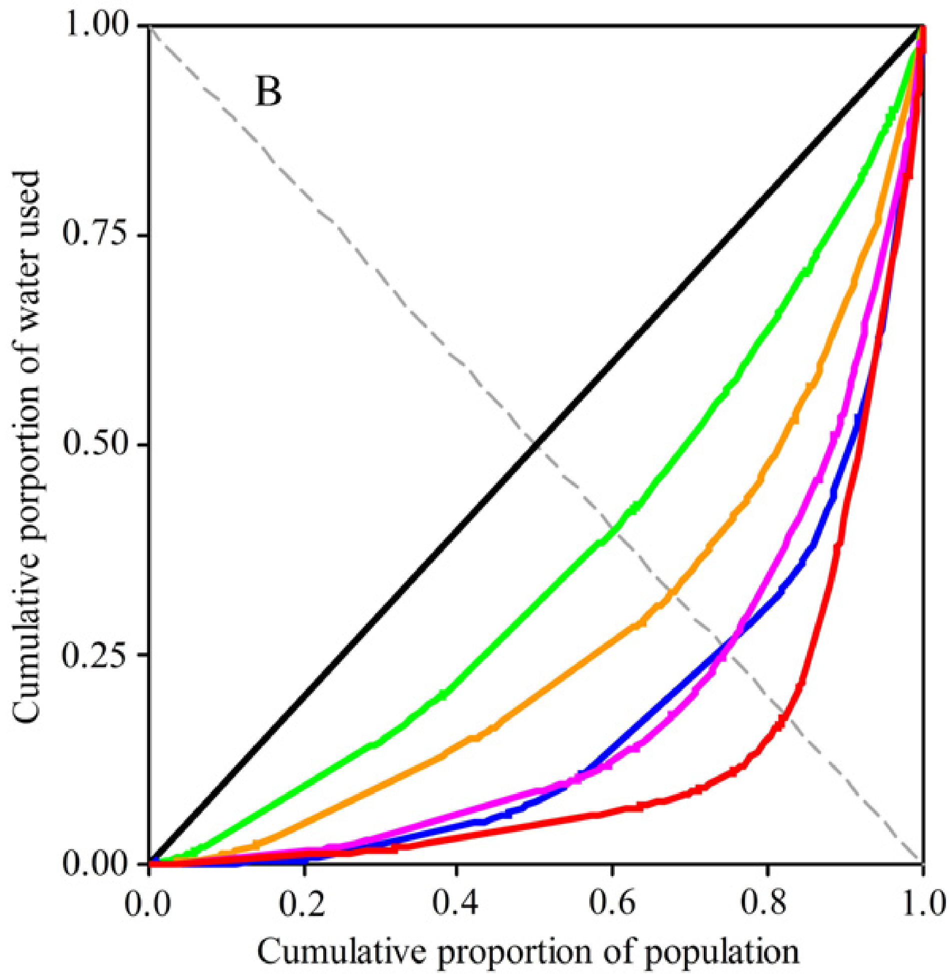
Global water scarcity

Global Water availability is sufficient to sustain food security for the world population. <u>Problem</u>: Water resources are unevenly distributed.

<u>Lorenz curves for five water components of water use.</u>
The **green** Lorenz curve is for the internal agricultural water footprint. The **orange** Lorenz curve is for household uses water footprint. The **blue** Lorenz curve is for the internal industrial water footprint. The **pink** Lorenz curve is for the external agricultural water footprint. The **red** Lorenz curve is for the external industrial water footprint.

D. A. Seekell, P D'Odorico and M L Pace (2011)



Virtual water: the concept

- Virtual water is the water 'embodied' in a product, not in real sense, but in virtual sense. It refers to the water needed for the production of the product. (Hoekstra)
- Virtual water content is nothing else as an life cycle accounting of water (similar to energy balance approaches etc.)
- The accounting framework requires the knowledge of the whole structure of the economy.
- In the case of a two-sector economy we have the following simple calculation:

	steel	cars
steel	a_{11}	a_{12}
cars	a_{21}	a_{22}
water	m_1	m_2

<u>virtual water (embedded water)</u>
(for $a_{21}=a_{22}=0$)

$v_1 = m_1/(1-a_{11})$	$v_2 = [a_{12}\, m_1/(1-a_{11})] + m_2$

Virtual water: the concept

Table 4.1. Virtual water content of a few selected products in m^3/ton. Estimates by different authors.

	Hoekstra & Hung (2003)*	Chapagain & Hoekstra (2003)*	Zimmer and Renault (2003)**	Oki *et al.* (2003)***
Wheat	1150	-	1160	2000
Rice	2656	-	1400	3600
Maize	450	-	710	1900
Potatoes	160	-	105	-
Soybean	2300	-	Egypt: 2750	2500
Beef	-	15977	13500	20700
Pork	-	5906	4600	5900
Poultry	-	2828	4100	4500
Eggs	-	4657	2700	3200
Milk	-	865	790	560
Cheese	-	5288	-	-

* The figures given represent global averages.
** Unless stated otherwise, the data refer to a study for California.
*** Data refer to Japan.

Hoeckstra, A. Y: water report 12, IHE Delft

Virtual water: the concept

<u>Water footprint for a closed economy</u>: domestic use of virtual water

In the case of a two-sector economy:

$WFP = x_1 v_1 + x_2 v_2$

<u>Water footprint for an open economy</u>:

WFP = domestic use + (import – export) =

WFP = domestic use + net virtual water import

= DU + NVWI

<u>Water scarcity</u>

WS = domestic use/water availability

<u>Water dependency</u>

WD = NVWI/(DU+NVWI) if NVWI ≥ 0, otherwise 0

<u>Water self-sufficiency</u>

WSS = DU/(DU+NVWI) if NVWI ≥ 0, otherwise 0

Hoeckstra, A. Y.: water report 12, IHE Delft

<u>The policy program of the virtual water approach</u>

- Virtual water studies show the importance of virtual water trade analysis in drafting water policy plans
- Virtual water trade between nations can relieve the pressure on scarce water resources and contribute to the mitigation of water scarcity.
- Virtual water trade should be encouraged to promote water savings.
- It seems wise to include virtual water accounting in any national or regional water and agricultural policy analysis. Common procedures of virtual water accounting should therefore be developed and disseminated.

A. Y. Hoeckstra (2003): Virtual water an introduction, in Hoeckstra (2003)

Virtual water trade

Table 5.4. Overview of the largest country contributions to global virtual water trade (period 1995-1999).

Global virtual water trade in relation to crop trade		Global virtual water trade in relation to trade of livestock and livestock products		Total global virtual water trade	
Net import	Net export	Net import	Net export	Net import	Net export
Sri Lanka 12%	Canada + USA 30%	Japan 9%	Australia + New Zealand 18%	Sri Lanka 9%	Canada + USA 24%
Japan 9%	Thailand 7%	Italy 8%	Canada + USA 9%	Japan 9%	Australia + New Zealand 8%

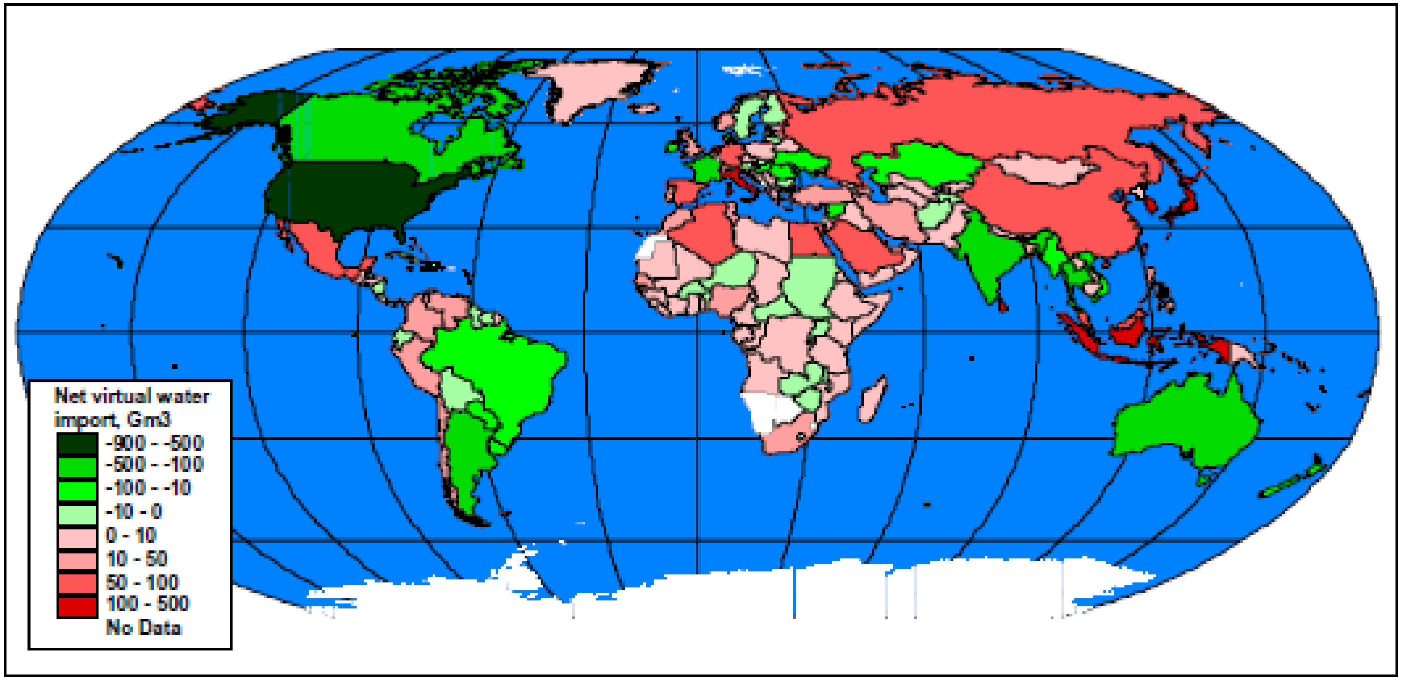


Figure 5.1. National virtual water trade balances over the period 1995-1999. Red represents net import, green net export.

Virtual water trade

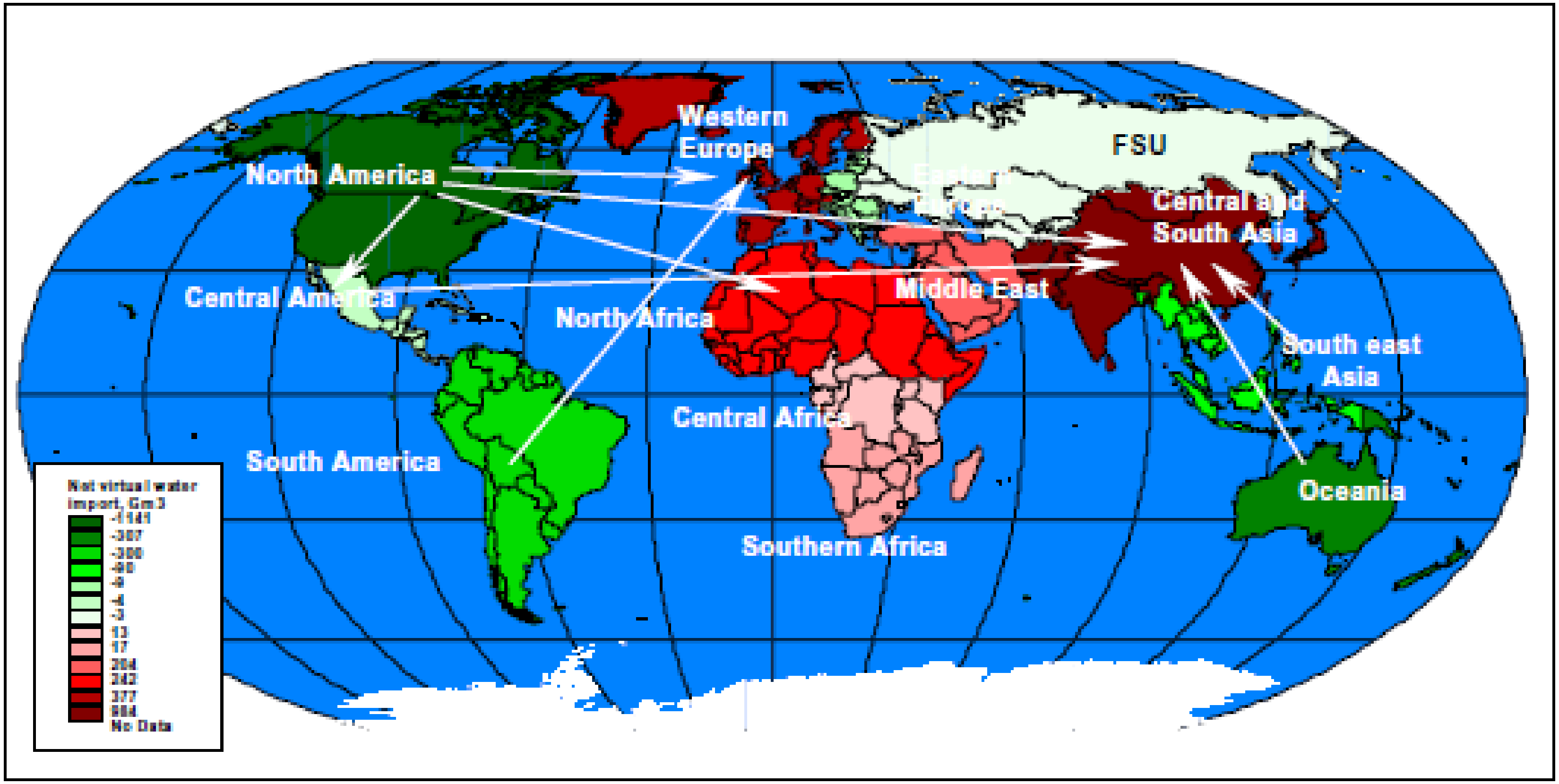


Figure 5.2. Virtual water trade balances of thirteen world regions over the period 1995-1999. The arrows show the largest net virtual water flows between regions (>100 Gm³).

Virtual water trade

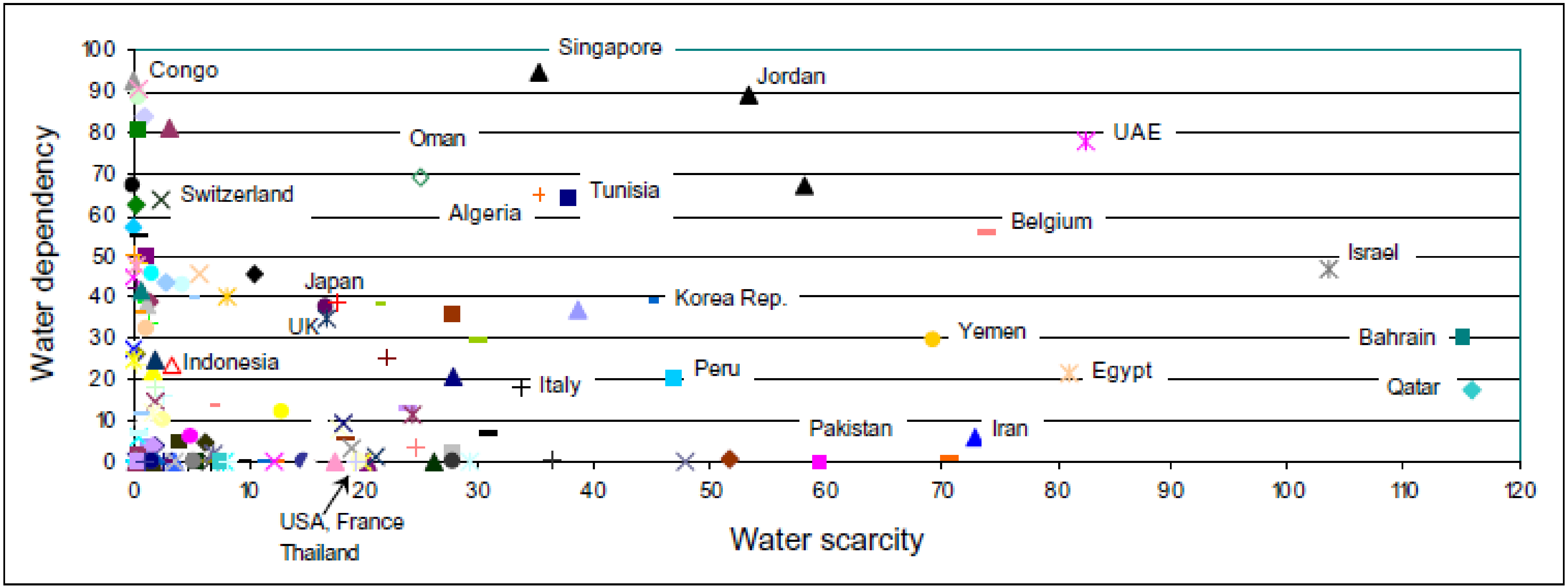
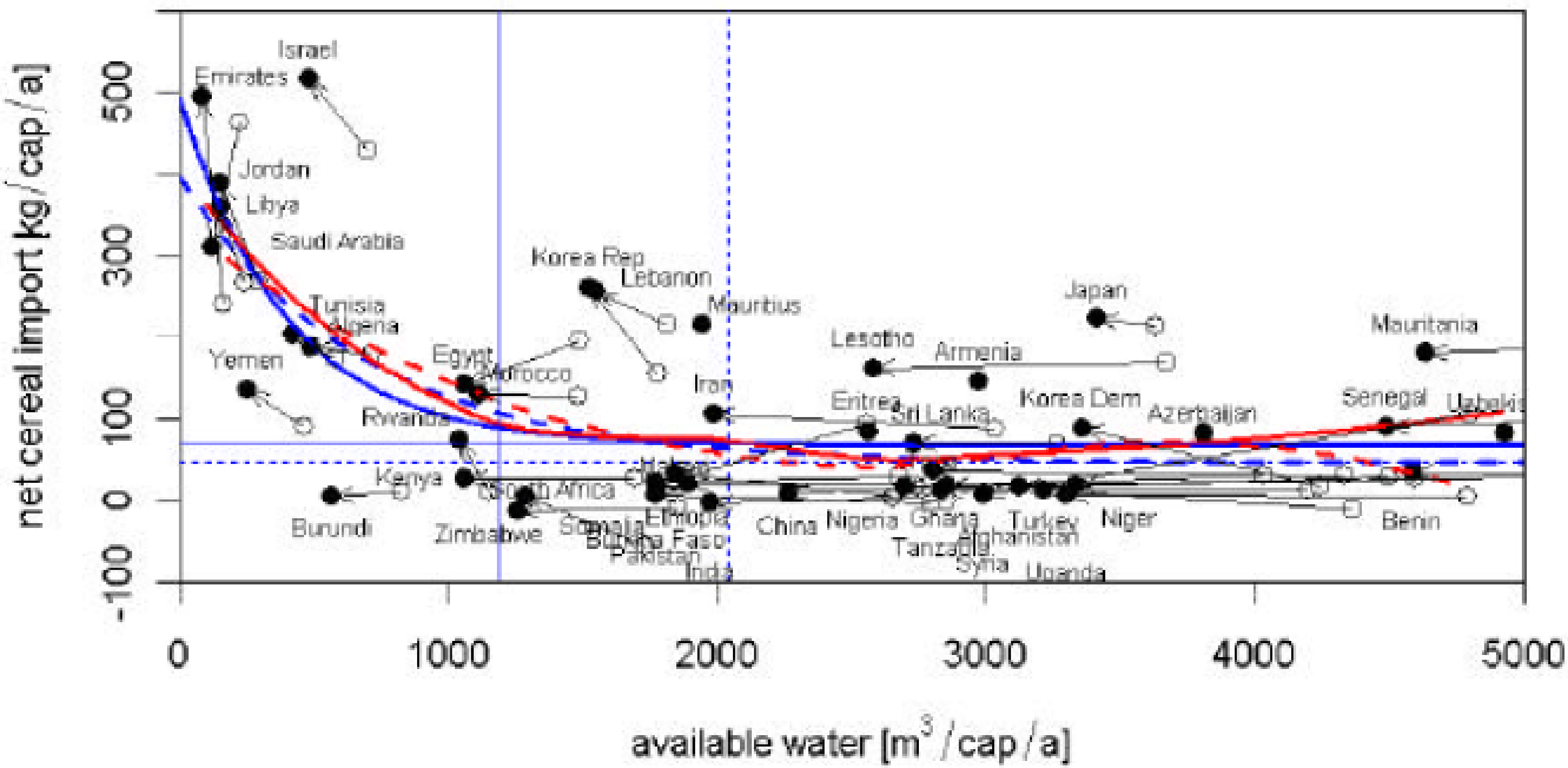


Figure 6.1. Water dependency versus water scarcity for all countries of the world (1995).

Hoekstra and Hung (2003), in A. Y. Hoekstra

virtual water trade



H. Yang, et al: A water resources threshold and its implications for food security in A. Y. Hoekstra report 2012, IHE Delft

Virtual water trade

<u>Empirical findings of Kumar and Singh (2005)</u>

• The cross-country analysis of virtual trade show that renewable water availability does not have any bearing on (virtual) water trade volume.

•Virtual water flow is controlled more by access to arable land

•The data samples show that virtual water often flows out of „water-poor“ but „land-rich“ country to „water-rich“ but „land-poor“ countries.

•Hence, food security must be discussed not only from a water resource perspective.

Trade models and virtual water

Ansink (2010), Wichelns (2004) have applied trade models to virtual trade. Trade policy implications are discussed by Gawel and Bernsen (2011)

Virtual trade in a Heckscher-Ohlin-model (Ansink)

•Two factor model (water (W), capital (K)), two goods (goods A and B), two countries (1 and 2)

•Country 1 is water abundant ($W_1/K_1 > W_2/K_2$)

•H-O-Theorem:

•A country exports the good which uses the country's more abundant factor more intensively.

•Corrolary:

•Each country is a net exporter of the country's more abundant factor and a net importer of the other factor.

Main virtual water trade theorem (Hoekstra, Allan)

Virtual water trade levels uneven water distribution (indirectly through trade)

Refuting virtual water theorem (Ainsink)

The corrolary refers to relative abundance (W/K), not to absolute scarcity between countries. Hence, a relative water abundant country (W1 > W2) can be a net importer.

Fair distribution of water resources

•The discussion on virtual water/ footprint/ net position has changed it‘s perspective.

• In the eighties virtual water trade was meant to increase the global water use efficiency (Allan)

•Later virtual water and the calculation of water footprints were established to provide a accounting framework as a prerequisite to implement resource fairness.

•Fairness and sustainability in water use require the establishment of both minimum water rights and maximum allowable levels of water use.

• Hence, water footprints quota should be introduced: allocation to nations not according to natural water endowment, but according to the philosophy of fair shares.

•The allocation key could be the population fraction.

fair distribution of water resources

- Each nation would have the obligation to move producers and consumers towards a production/consumption pattern that fits within national quota
- This goal can be achieved by classic environmental policy instruments like subsidies, taxes, regulation etc.
- (Obviously, there is no possibility to trade water shares (certificates))
- There is also the “water-neutral concept”. Each person (nation) pays a “justified amount” of money for it’s water footprint .

A..Y.Hoekstra (2011): Global dimension

A textbook model of virtual water trade

A Ricardo-model with one resource (water) and two goods (beef, soybean) and two countries(country one: water scarce, country two water abundant)

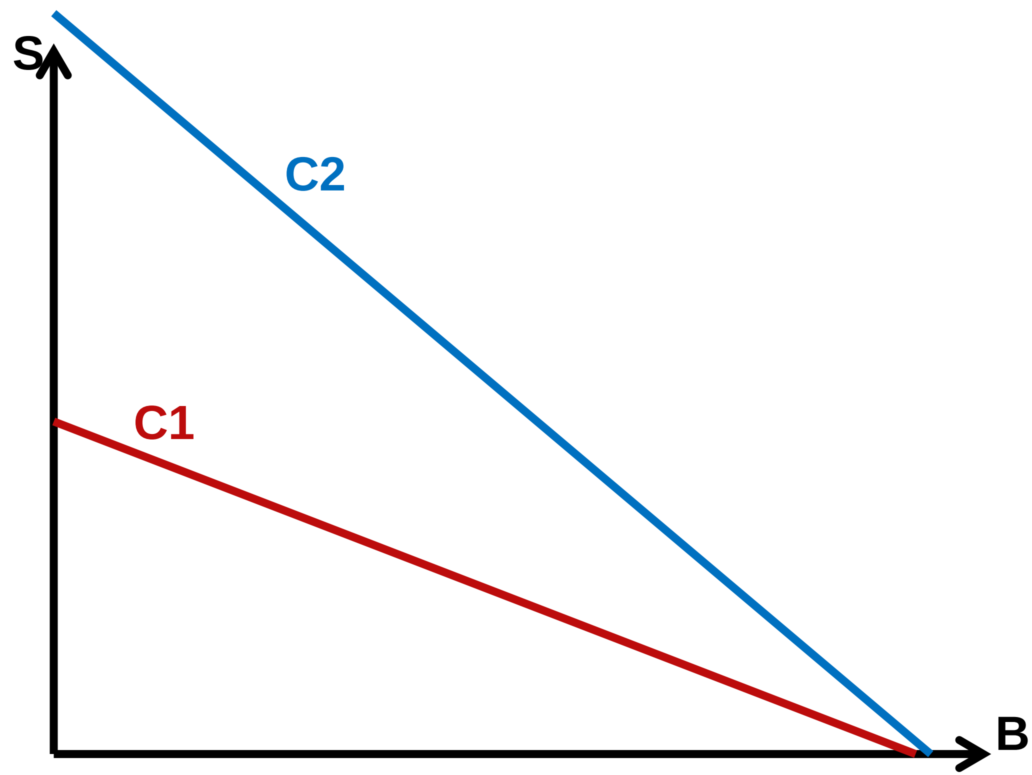
	beef	soybean
Country 1	a_{1B}	a_{1S}
Country 2	a_{2B}	a_{2S}

example:
a_{1B} = beef/water
water productivity (efficiency)

<u>production frontiers</u>
country 1: $B_1/a_{1B} + S_1/a_{1S} = W_1$
country 2: $B_2/a_{2B} + S_2/a_{2S} = W_2$
$W_1 < W_2$

comparative advantages

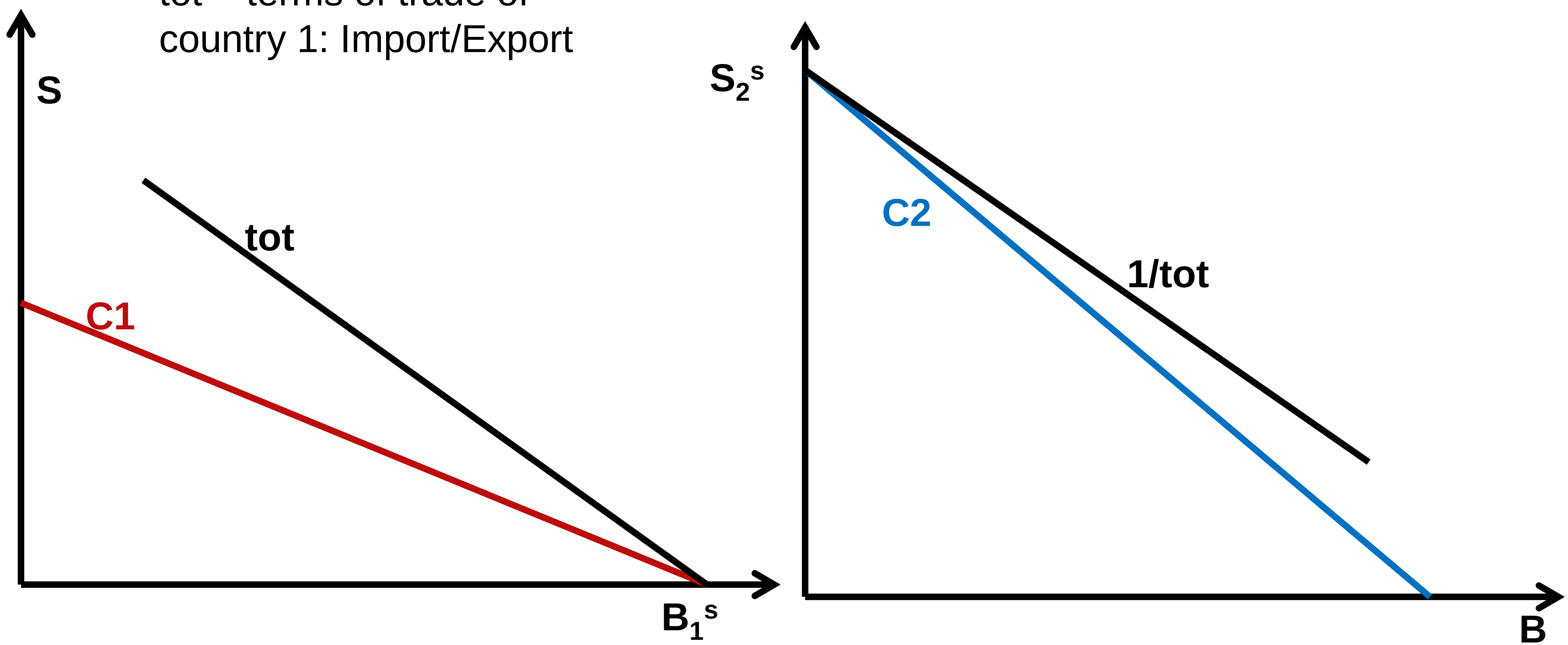
$$-\frac{dS2}{dB2} = \frac{a2S}{a2B} > \frac{a1S}{a1B} = -\frac{dS1}{dB1}$$



A textbook model of virtual water trade

Comparative advantages determine the international specialization:
Country 1: production of beef: $B_1^s = a_{1B} W_1$
Country 2: production of soybean: $S_2^s = a_{2S} W_2$

tot = terms of trade of country 1: Import/Export



A textbook model of virtual water trade

Country 1: demand

Max $U(B_1,S_1)$ s.t. $p_B\, B_1 + p_S\, S_1 = Y_1$

Assume Cobb-Douglas-Function $U(B_1,S_1) = (B_1)^{\alpha}(S_1)^{(1-\alpha)}$

demand functions

$B_1 = \alpha\, (Y_1/p_B)$, where $Y_1 = p_B\, B_1^s\ = p_B\, a_{1B}\, W_1$

$\mathbf{B_1 = \alpha\, a_{1B}\, W_1}$

analogous :

$S_1 = (1\text{-}\alpha)\, (Y_1/p_S) =\ (1\text{-}\alpha)\, (p_B\, a_{1B}\, W_1\, /p_S)$

$\mathbf{S_1 = (1\text{-}\alpha)\, (a_{1B}\, W_1\, \pi)}$

where π = tot = p_B/p_S

Country 2: demand

Max $U(B_2,S_1)$ s.t. $p_B\, B_1 + p_S\, S_1 = Y_1$

Assume Cobb-Douglas-Function $U(B_1,S_1) = (B_1)^{\alpha}(S_1)^{(1-\alpha)}$

demand functions

$B_1 = \alpha\, (Y_1/p_B)$, where $Y_1 = p_B\, B_1^s\ = p_B\, a_{1B}\, W_1$

$\mathbf{B_2 = \beta\, a_{2S}\, W_2/\pi}$

where $1/\pi$ = tot = p_S/p_B

analogous :

$S_2 = (1\text{-}\alpha)\, (Y_1/p_S) = = (1\text{-}\alpha)\, (p_B\, a_{1B}\, W_1\, /p_S)$

$\mathbf{S_2 = (1\text{-}\beta)\, (a_{2S}\, W_2)}$

A textbook model of virtual water trade

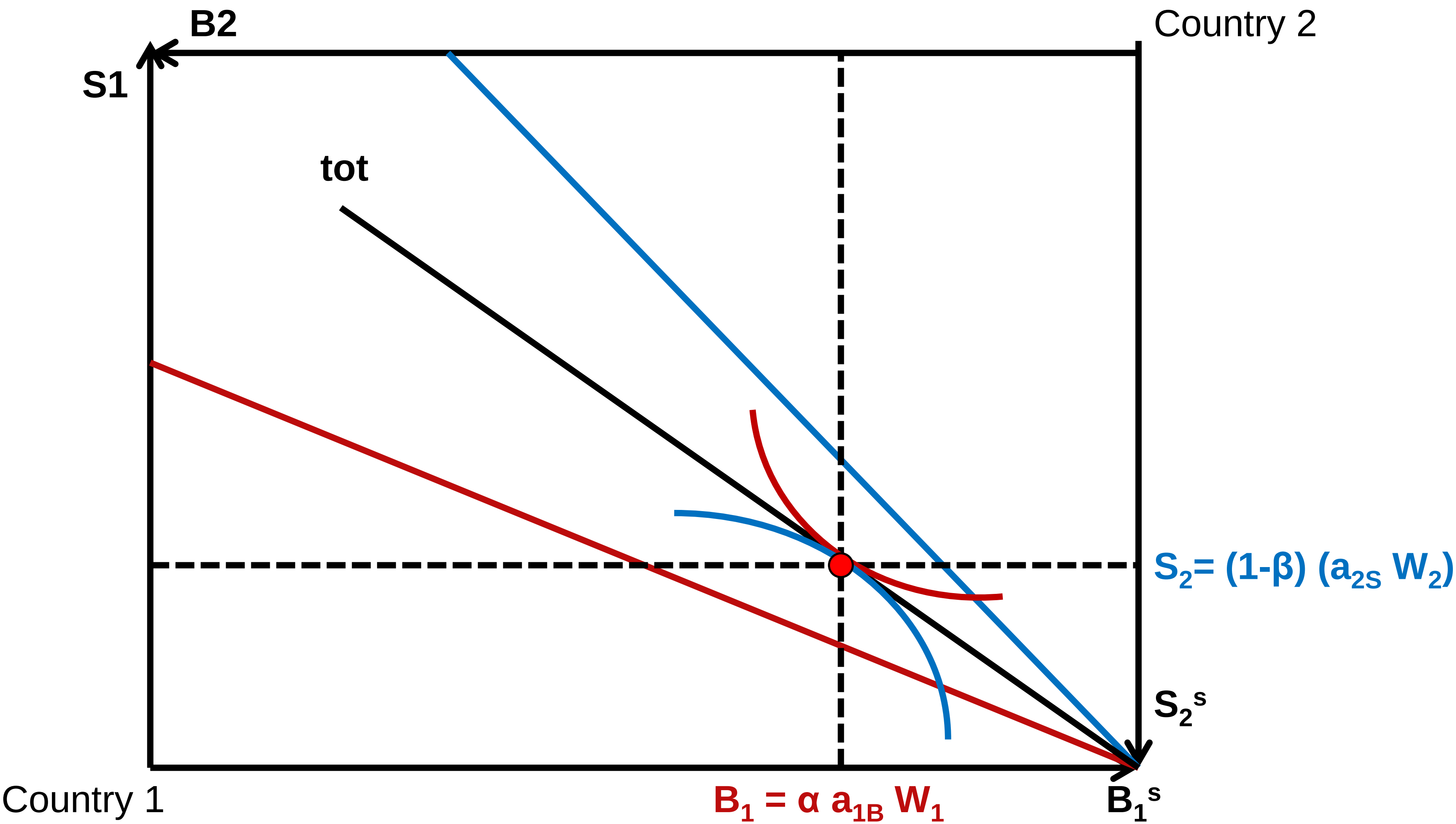
Country 1: balance of trade
$p_B\,(B_1^s - B_1) - p_S\,S_1 = 0$,
budget line:
$S_1 = (p_B/p_S)\,(B_1^s - B_1) = \pi\,(B_1^s - B_1)$
π = terms of trade

Country 2: balance of trade
$p_S\,(S_2^s - S_2) - p_B\,B_2 = 0$,
budget line:
$S_2 = S_2^s - B_2/\pi$
$1/\pi$ = terms of trade

Determination of equilibrium terms of trade:
$B1 + B2 = \mathbf{B_1^s}$

$$\pi = \frac{\beta\, a2S\, W2}{(1-\alpha)\, a1B\, W1}$$

A textbook model of virtual water trade



A textbook model of virtual water trade

Country 1: water footprint (WFP)

WFP_1 = home production – export + import

$= W_1 - (W_1 - B_1/a_{1B}) + S_1/a_{2S} =$

$WFP_1 = \alpha W_1 + (1-\alpha)(a_{1B} W_1 \pi) =$

$\mathbf{WFP_1 = \alpha W_1 + \beta W_2}$

Country 2: water footprint (WFP)

WFP_2 = home production – export + import

$= W_2 - (W_2 - S_2/a_{2S}) + B_2/a_{1B} =$

$WFP_2 = (1-\beta) W_2 + \beta a_{2S} W_2/\pi =$

$\mathbf{WFP_2 = (1-\alpha) W_1 + (1-\beta) W_2}$

Country 1: virtual water net position

$NP_1 = WFP_1 - W_1$

$\mathbf{NP_1 = \beta W_2 - (1-\alpha) W_1}$

Net exporter: $NP_1 < 0$

Net importer $NP_1 > 0$

Country 2: virtual water net position

$NP_2 = WFP_2 - W_2$

$\mathbf{NP_2 = (1-\alpha) W_1 - \beta W_2}$

Net exporter: $NP_2 < 0$

Net importer $NP_2 > 0$

• <u>Result 1</u>

There is no stable relation between countries welfare and its net position of water. Taking up trade can lead to a negative net position of an water scarce country (country 1) while increasing welfare. Water saving/net gains in water etc. are neither necessary nor sufficient for the welfare enhancing effects of trade.

<u>Proof</u>: Trade increases welfare regardless of the water net position of the countries.

<u>Example:</u> Trade is welfare enhancing iff $\pi > a_{1S}/a_{1B.}$ The net position is negative (virtual water export) if $\beta/(1-\alpha) \leq W_1/W_2$. Both conditions lead to $a_{2S} > a_{1S}$, i.e. the water efficiency of the importing country 2 is higher than that of the exporting country 1.

• **Results 2**:

The net position is not only determined by relative water scarcity but also by the demand for export/import goods

Proof: The net position of country 1 is:

$$NP_1 = \beta W_2 - (1-\alpha) W_1$$

which depends not only on the natural endowment of water but also on income share of expenses for beef (export good of country 1) and for soybean (import good of country 1)

Establishing fairness by introducing water footprint quotas

- Fairness could be achieved by a fair distribution of water resource property rights.
- Since water resources can not be transferred, property rights refer to the entitlement of a portion of economic rents of water resources.
- The allocation key could be the population share.

Ricardo-model

Fair water resource allotment:

$WR_1 = (n_1/N)(W_1+W_2)$; $WR_2 = (n_2/N)(W_1+W_2)$, $N = n_1 + n_2$

Economic rents of water resources are:

Country 1: $q_1 W_1$; country 2: $q_2 W_2$

Perfect competition implies to

$p_B B_1^S = q_1 W_1$ and $p_S S_2^S = q_2 W_2$

Hence

$Y_1 = v_1 p_B B_1^S + v_1 p_S S_2^S$ and $Y_2 = v_2 p_B B_1^S + v_2 p_S S_2^S$,

where $v_1 = n_1/N$, $v_2 = n_2/N$

A textbook model of virtual water trade

Inserting into the demand function leads to:

Country 1:

$B_1 = \alpha\, v_1\, (B_1^S + S_2^S/\pi)$; $S_1 = (1-\alpha)\, v_1\, (\pi B_1^S + S_2^S)$

Country 2:

$B_2 = (1-v_1)\beta[B_1^S + S_2^S/\pi]$ $S_2 = (1-v_1)(1-\beta)(\pi B_1^S + S_2^S)$

Equilibrium terms of trade follow from the market equilibrium:

$B_1 + B_2 = B_1^S$

$$\pi = \frac{v1[(\alpha-\beta)+\beta]a2S\, W2}{[v1(\beta-\alpha)+(1-\beta)]a1B\, W1}$$

Country 1 water footprint:

WFP_1 = home production – export + import

$= W_1 - (W_1 - B_1/a_{1B}) + S_1/a_{2S} =$

$$\mathbf{WFP_1} = \frac{v1\,\alpha}{v1(\alpha-\beta)+\beta}W1 + \frac{(1-\alpha)v1}{v1(\beta-\alpha)+(1-\beta)}W2$$

Country 1: virtual water net position

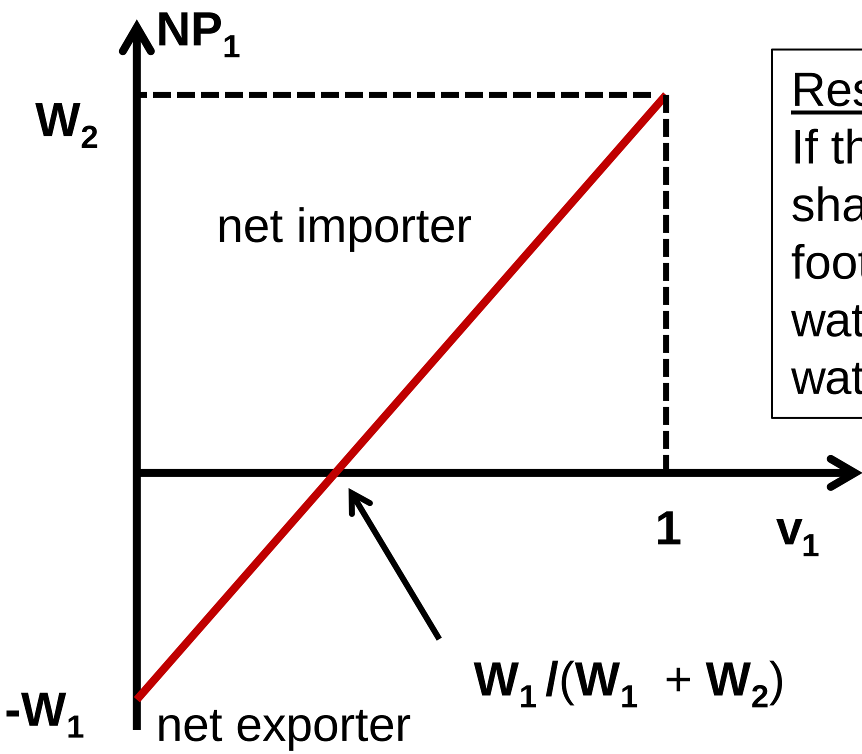
$NP1 = WFP_1 - W_1$

$$\mathbf{NP_1} = \frac{(1-\alpha)v1}{v1(\beta-\alpha)+(1-\beta)}W2 - \frac{(1-v1)\beta}{v1(\alpha-\beta)+\beta}W1$$

two cases

Case 1: identical demand (i.e. $\alpha = \beta$)

$NP_1 = v_1 W_2 - (1-v_1) W_1$

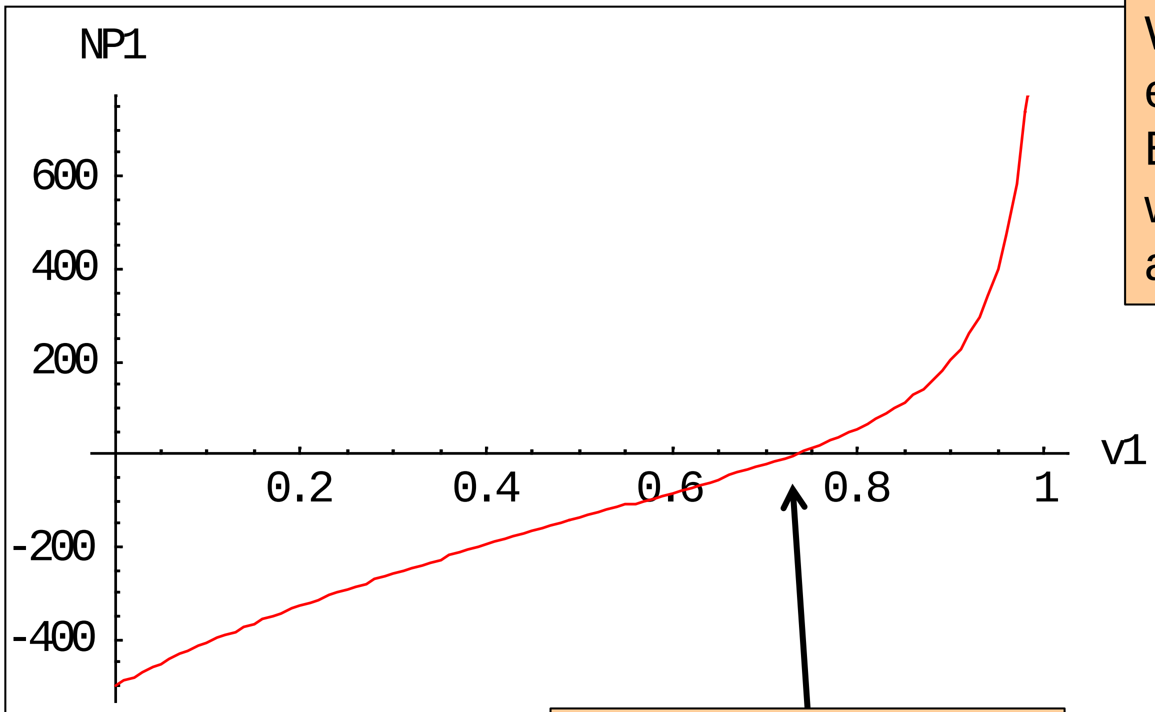


Result:
If the share of population v_1 is greater than the share of (real) water resources then water footprint quotas makes the highly populated and water scarce country a net importer of virtual water.

two cases

Case 2: heterogenous demand (i.e. α ≠ β)

$$NP_1 = \frac{(1-\alpha)v1}{v1(\beta-\alpha)+(1-\beta)}W2 - \frac{(1-v1)\beta}{v1(\alpha-\beta)+\beta}W1$$



NP-threshold = 0.73

Example:
water scarce country (W_1 = 500, W_2 = 1500, low demand for own export good (beef): a =0.9, b = 0.5
Even under a fair share of global water resources the county might be a virtual water net exporter

Without property right policy country 1 is a virtual water net importer (+745)

Results

- Virtual water net positions are no indicators for fairness of water resource distribution
- The fair quota system based on relative population shares leads to an new issue of environmental policy: should population growth be part of the sustainability concept?

Summary: Implications for a sustainable water policy

•Each country should pursue a sustainable water policy directed toward it‘s own water resources. The main issue is whether available water resources are managed in a sustainable way!

•Trade policy as an instrument for water policy will fail due to the absence of relevant relations between trade, water footprints and virtual water net positions.

•The main instrument to achieve a sustainable water policy is to establish a proper water price.

•If global resource fairness is at stake: There is no apriori reason to confine the issue of a fair distribution of global resource usage to water. In terms of allover fairness all relevant resources have to be included. (But this is utopian).

Thank you!

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