# Economic and Political Equilibrium for a Renewable Natural Resource with International Trade

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## Introduction

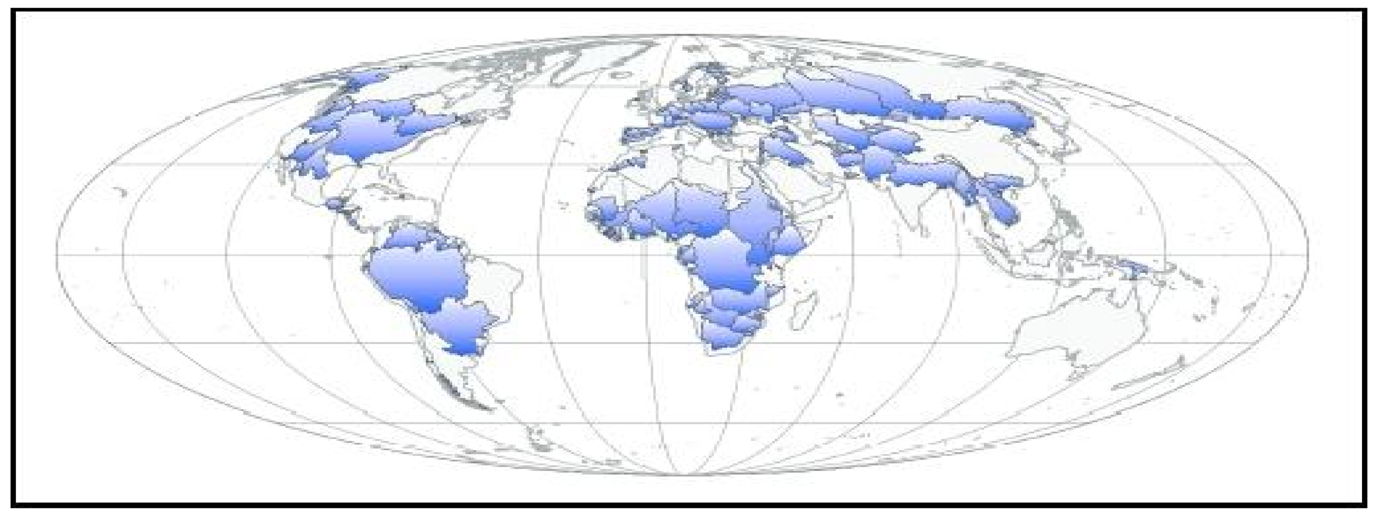


*Figure: International River Basins*
*Source: Wolf et al.(1999),International river basins of the world*

International resources such as water are typically subject to conflict as individual countries perceive individual gains from increased use of the resource. This inherent conflict is also reflected in analytical studies which are typically partial equilibrium and hence naturally assume that welfare functions are increasing in the resource allocation. In this setting, the question arises if there are ever circumstances such that it is in the joint self-interest of political entities to share the resource.

### Literature Review

Self-enforcing international environmental agreement (IEAs) and river basin management assumes a particular welfare function:

- Cooperative game theory
  - Ambec and Sprumont(2002): assumes strictly increasing and concave welfare function
  - Ambec and Ehlers(2008): assumes satiable welfare functions
- Noncooperative game theory
  - Ansink (2009): self-enforcing agreements on water allocation based on the outcome of a bargaining game

### Two stage Model

**Stage 1**: Given resource allocation, solve a 2-country, 2-good Ricardian trade model to obtain the welfare as functions of water allocation.

**Stage 2**: With the welfare functions derived, obtain the Nash equilibrium to the 2-country-2-strategy game.

## Model Setup

Two countries share an international river basin and engage in Ricardian trade.
Countries: i=1,2; goods: j=1,2.
Total amount of water: W
Water allocated to country i: $W_i = \theta_i W$ ,where $\theta_1 + \theta_2 = 1$

| Utility function | Production function | Resource constraint |
|---|---|---|
| $U_i = c_{i1}^{\alpha} c_{i2}^{1-\alpha}$ , $0<\alpha<1$ | $y_{ij} = \beta_{ij} w_{ij}$ | $\sum_{j=1}^{2} w_{ij} = W_i$ |

$\frac{\beta_{12}}{\beta_{11}} < \frac{\beta_{22}}{\beta_{21}}$ Comparative assumption: country 1 has a comparative advantage in good 1 and country 2 has a comparative advantage in good 2.

## Autarky

### The autarky problem

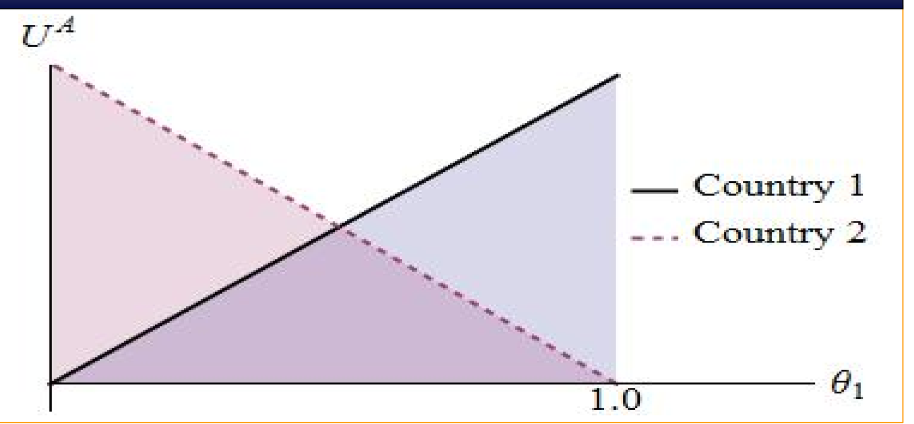
$$\max\ U_i = c_{i1}^{\alpha} c_{i2}^{1-\alpha}$$
$$\text{s.t. } c_{ij} = y_{ij} = \beta_{ij} w_{ij},\quad j = 1,2$$
$$w_{i1} + w_{i2} = \theta_i W$$

### Autarky welfare function

$$U_i^A(\theta_i) = (\alpha\beta_{i1})^{\alpha}((1-\alpha)\beta_{i2})^{1-\alpha}\theta_i W$$

### Autarky price ratio

$$\overline{p}_{i2} / \overline{p}_{i1} = \beta_{i2} / \beta_{i1}$$



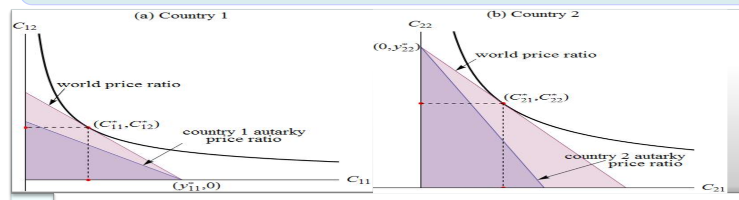

## Free Trade

### The free trade problem

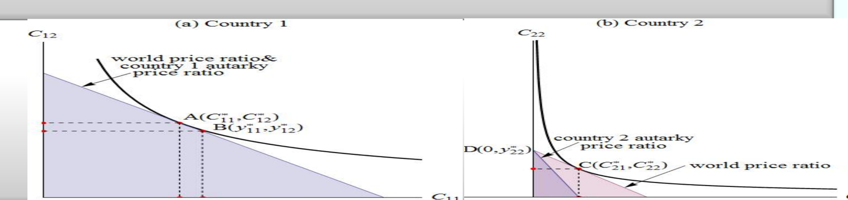
$$\max\quad U_i = c_{i1}^{\alpha} c_{i2}^{1-\alpha}$$
$$\text{s.t.}\quad p_1 c_{i1} + p_2 c_{i2} = p_1 y_{i1}^* + p_2 y_{i2}^*$$
$$y_{ij} = \beta_{ij} w_{ij}$$
$$w_{i1} + w_{i2} = \theta_i W$$

Equilibrium world $p_j$ clear the goods market: $y_{1j}^* + y_{2j}^* = c_{1j}^* + c_{2j}^*$

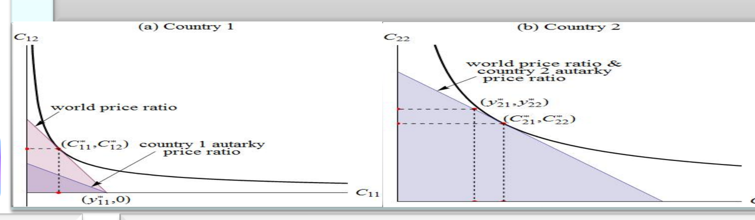
### Three cases of relative water allocation:



Case 1: Intermediate water allocation
Equilibrium world price ratio: $\beta_{12}/\beta_{11} = \overline{p}_{11}/\overline{p}_{12} < p_1/p_2 < \overline{p}_{21}/\overline{p}_{22} = \beta_{22}/\beta_{21}$



Case 2: Large country 1 water allocation
Equilibrium world price ratio: $p_1/p_2 = \beta_{12}/\beta_{11}$



Case 3: Small country 1 water allocation
Equilibrium world price ratio: $p_1/p_2 = \beta_{22}/\beta_{21}$

### The free trade welfare function

**Case 1:** $\frac{\alpha\beta_{21}}{\alpha\beta_{21} + (1-\alpha)\beta_{11}} < \theta_1 < \frac{\alpha\beta_{22}}{\alpha\beta_{22} + (1-\alpha)\beta_{12}}$

$$(U_1^{ft})_1 = (\beta_{11}\theta_1)^{\alpha}(\beta_{22}(1-\theta_1))^{1-\alpha}\alpha W$$
$$(U_2^{ft})_1 = (\beta_{11}\theta_1)^{\alpha}(\beta_{22}(1-\theta_1))^{1-\alpha}(1-\alpha) W$$

**Case 2:** $\theta_1 \geq \frac{\alpha\beta_{22}}{\alpha\beta_{22} + (1-\alpha)\beta_{12}}$

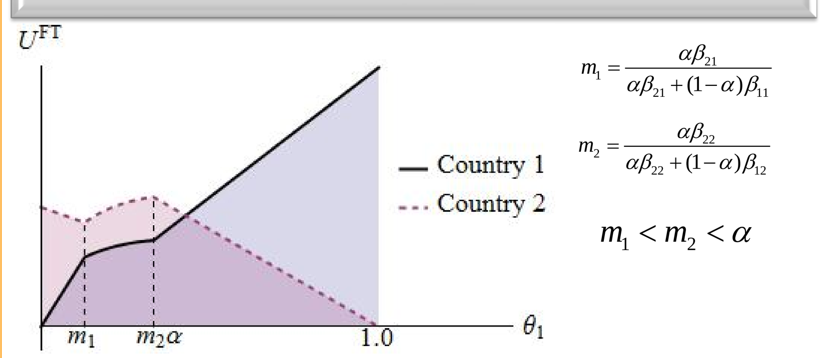
$$(U_1^{ft})_2 = U_1^A = (\alpha\beta_{11})^{\alpha}((1-\alpha)\beta_{12})^{1-\alpha}\theta_1 W$$
$$(U_2^{ft})_2 = (\frac{\beta_{11}}{\beta_{12}}\alpha)^{\alpha}(1-\alpha)^{1-\alpha}\beta_{22}(1-\theta_1) W$$

**Case 3:** $\theta_1 < \frac{\alpha\beta_{21}}{\alpha\beta_{21} + (1-\alpha)\beta_{11}}$

$$(U_1^{ft})_3 = \alpha^{\alpha}(\frac{\beta_{22}}{\beta_{21}}(1-\alpha))^{1-\alpha}\beta_{11}\theta_1 W$$
$$(U_2^{ft})_3 = U_2^A = (\alpha\beta_{21})^{\alpha}((1-\alpha)\beta_{22})^{1-\alpha}(1-\theta_1) W$$

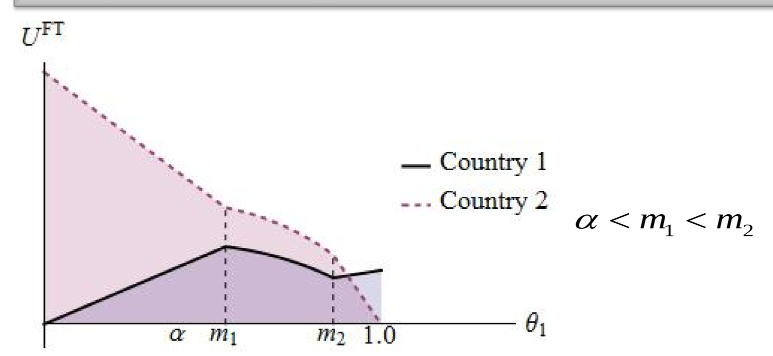
The graphs of the welfare functions has three cases depending on the parameterization.

**Case P1:** $\beta_{11} > \beta_{21}$ and $\beta_{12} > \beta_{22}$



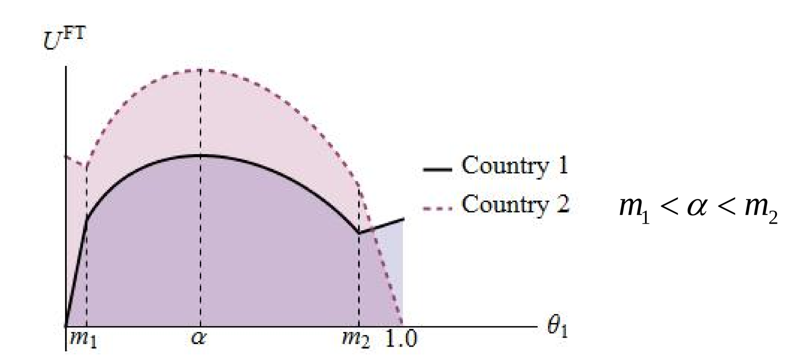

- Country 1 has absolute advantage in both goods.
- Country1's welfare function is monotonically increasing
- Country 2's welfare function has decreasing segment.

**Case P2:** $\beta_{11} < \beta_{21}$ and $\beta_{12} < \beta_{22}$




- Country 2 has absolute advantage in both goods.
- Country2's welfare function is monotonically increasing
- Country 1's welfare function has decreasing segment.

**Case P3:** $\beta_{11} > \beta_{21}$ and $\beta_{12} < \beta_{22}$




- Country 1 has comparative advantage in good 1, country 2 has comparative advantage in good 2. No absolute advantages.
- It's in both countries' mutual interest to share water.

### Water valuation under autarky and free trade

Under free trade, with intermediate water allocation, the welfare functions are either

- declining
- or less steeply sloped than under autarky (marginal valuation of water declines)

### Conflict and cooperation

- With declining welfare functions, the country would be willing to give up water out of its own interest.
- Even if it's not declining, the lower marginal value of water will reduce the level of conflict.

## Bargaining and Political Equilibrium

Given the welfare functions derived in the first stage, we obtain the Nash equilibrium to the two-country game where country 1 determines the water allocation and country 2 determines whether to open to trade or not.

**Table 1:** General Payoff Matrix

| | | Country 2: Autarky | Country 2: Free Trade |
|---|---|---|---|
| Country 1 | $\theta_1 = \theta_{low}$ | $(U_1^A\theta_{low}, U_2^A(\theta_{low}))$ | $(U_1^{FT}(\theta_{low}), U_2^{FT}(\theta_{low}))$ |
| | $\theta_1 = \theta_{high}$ | $(U_1^A\theta_{high}, U_2^A(\theta_{high}))$ | $(U_1^{FT}(\theta_{high}), U_2^{FT}(\theta_{high}))$ |

The results differ with:
(1)different strategy specifications, i.e. the water allocation parameters for country 1 to choose from
(2) production parameter values, which will result in different welfare functions.

**Table 2:** Payoff Matrix when Country 1's welfare increases with $\theta_1$
(with $\beta_{11} = 9, \beta_{12} = 8, \beta_{21} = 2, \beta_{22} = 6$)

| | | Country 2: Autarky | Country 2: Free Trade |
|---|---|---|---|
| Country 1 | $\theta_1 = \theta_{low} = 0.2$ | (0.8556,1.5780) | (1.2969,1.9454) |
| | $\theta_1 = \theta_{high} = 0.3$ | (1.2835,1.3808) | (1.4079,2.1118) |

**Table 3:** Payoff Matrix when Country 1's welfare decreases with $\theta_1$
(with $\beta_{11} = 4, \beta_{12} = 1, \beta_{21} = 7, \beta_{22} = 9$)

| | | Country 2: Autarky | Country 2: Free Trade |
|---|---|---|---|
| Country 1 | $\theta_1 = \theta_{low} = 0.6$ | (0.5330,1.6610) | (1.2244,1.8366) |
| | $\theta_1 = \theta_{high} = 0.8$ | (0.7106,0.8305) | (0.9063,1.3595) |

## Conclusion

When riparian countries are engaged in free trade, and for certain parameter specifications, there are circumstances in which country welfare can actually be decreasing in water allocation. Hence, it would be in the countries' self-interest to share water. Furthermore, even if the welfare function is increasing in water allocation, trade means that the gains from additional water can be smaller than that under autarky.
In general , moving to a general equilibrium setting can potentially be conflict-reducing, although not necessarily conflict-eliminating. This is due to the fact that in general equilibrium, there can be additional channels through which water allocation affects an entity, and some of these may be adverse. Furthermore, in some circumstances policies not directly related to water may be used to leverage additional resource allocation.

## Current work

We extend the Ricardian free trade model by allowing continuous trade policies, such as quotas. Introduction of an import constraint (country 2 here), necessitates a number of structural changes compared to the free-trade Ricardian model in the paper.

- There is no necessary unique world price, instead there are separate goods markets in each country which may or may not have the same price for a particular good.
- We introduce a transhipment variable to specify exactly country of origin and destination.
- To implement the import constraint in the equilibrium framework, we introduce a market for import quotas, with households holding the property rights.

This model has five markets. Accordingly, we rely on numerical methods (Negishi format) to calculate equilibrium.

### The problem

$$\max\quad U_i = (c_{i1}^{\alpha 1} c_{i2}^{1-\alpha 1})^{\alpha 0},\ \text{s.t.}$$
$$\sum_{j=1,2} p_{1j} c_{1j} = \sum_{i2=1,2}\sum_{j=1,2} p_{i2,j} x_{1,i2,j} - p_{lic} x_{1,2,1}$$
$$\sum_{j=1,2} p_{2j} c_{2j} = \sum_{i2=1,2}\sum_{j=1,2} p_{i2,j} x_{2,i2,j} + p_{lic} x_{1,2,1}$$
$$\sum_{i2=1,2} x_{i,i2,j} = y_{ij} = \beta_{ij} w_{ij}$$
$$\sum_{j=1,2} w_{ij} = W_i \quad \text{for } i = 1,2$$

Equilibrium prices clear the goods market and the import quota market:

$$c_{ij} = \sum_{i1=1,2} x_{i1,i,j},\quad x_{1,2,1} \leq \overline{x}$$

### The Negishi format

$$\max\quad \phi U_1 + (1-\phi) U_2$$
$$\text{s.t.}\quad \sum_{i2=1,2} x_{i,i2,j} = y_{ij},\quad \text{for } i = 1,2,\ j = 1,2$$
$$x_{1,2,1} \leq \overline{x}$$
$$y_{ij} = \beta_{ij} w_{ij}$$
$$\sum_{j=1,2} w_{ij} = W_i \quad \text{for } i = 1,2$$
$$c_{ij} = \sum_{i1=1,2} x_{i1,i,j}$$

Iterating over the welfare weight $\phi$ until the budget constraint is satisfied.

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