Water-resource use and conflict in a two-sector evolutionary model

A. Antoci (University of Sassari)
S. Borghesi (University of Siena)*
M. Sodini (University of Pisa)

Italian Association of Environmental and Resource Economists
4th Annual Conference, 11-12 February 2016, Bologna

Overview

* Over the last few years the growing problems of water scarcity and water pollution have attracted increasing attention
* Water conflicts/competition both across countries (e.g. Ciad-Nigeria-Camerun, Israel vs. Jordan, Siria vs. Turkey etc…) and within countries (among competing populations/firms/sectors)
* To deal with these problems the introduction of a system of market incentives (and disincentives) in water management has been proposed

Water tradable permits: applications

* Water tradable pollution rights (WTPR): mainly US (Colorado, California, Wisconsin etc…) and Australia (Murray-Darling basin)
* Water tradable abstraction rights (WTAR): US, Australia but also Chile, Mexico and other LDCs
* Mixed results: some experiences very successful (e.g. Murray-Darling basin, Idaho, California), others unsuccessful (small number transactions in Wisconsin, Colorado…)

Related Literature

- Huge literature on ETS (mainly on GHG emission trading)
- Vast literature on water applications (mainly case studies): Borghesi (2013, JEPM), Fisher-Vanden and Olmstead (2013, JEP) for surveys on WTPR and WTAR
- Recent empirical studies on invention and diffusion of water supply and water efficiency technologies (Conway et al., 2015)
- Small subset of theoretical models on water trading (mainly simulations)
- This paper: Study consequences of a market for water-use permits in the presence of a population of interacting economic agents characterized by imitative behaviours

Aim of the paper

* investigate the theoretical framework underlying the application of water tradable permits by proposing a dynamic evolutionary model to capture: (i) water competition among sectors and (ii) bounded rationality among economic agents
* Two-sector model with replicator dynamics

  Antoci, Borghesi, Sodini, 2014. "ETS and technological innovation: a random matching model", Handbook Climate Change, Oxford University Press

  Antoci, Borghesi, Russu, Ticci, 2015: 2-sector model on FDI (Ecol Econ)

A TWO-SECTOR MODEL

* 2 sectors: A and B
* Population of agents
* The size of the population is constant and represented by the positive parameter N
* the variable $x(t)$ indicates the share of the population working in sector A at time t (so $1 \geq x(t) \geq 0$, and $1-x(t)$ indicates the share of the population working in sector B)
* The production activities in both sectors depend on the stock W_i (i=A,B) of available water resources (W_i can also be interpreted as an index that takes water "quality" into account)

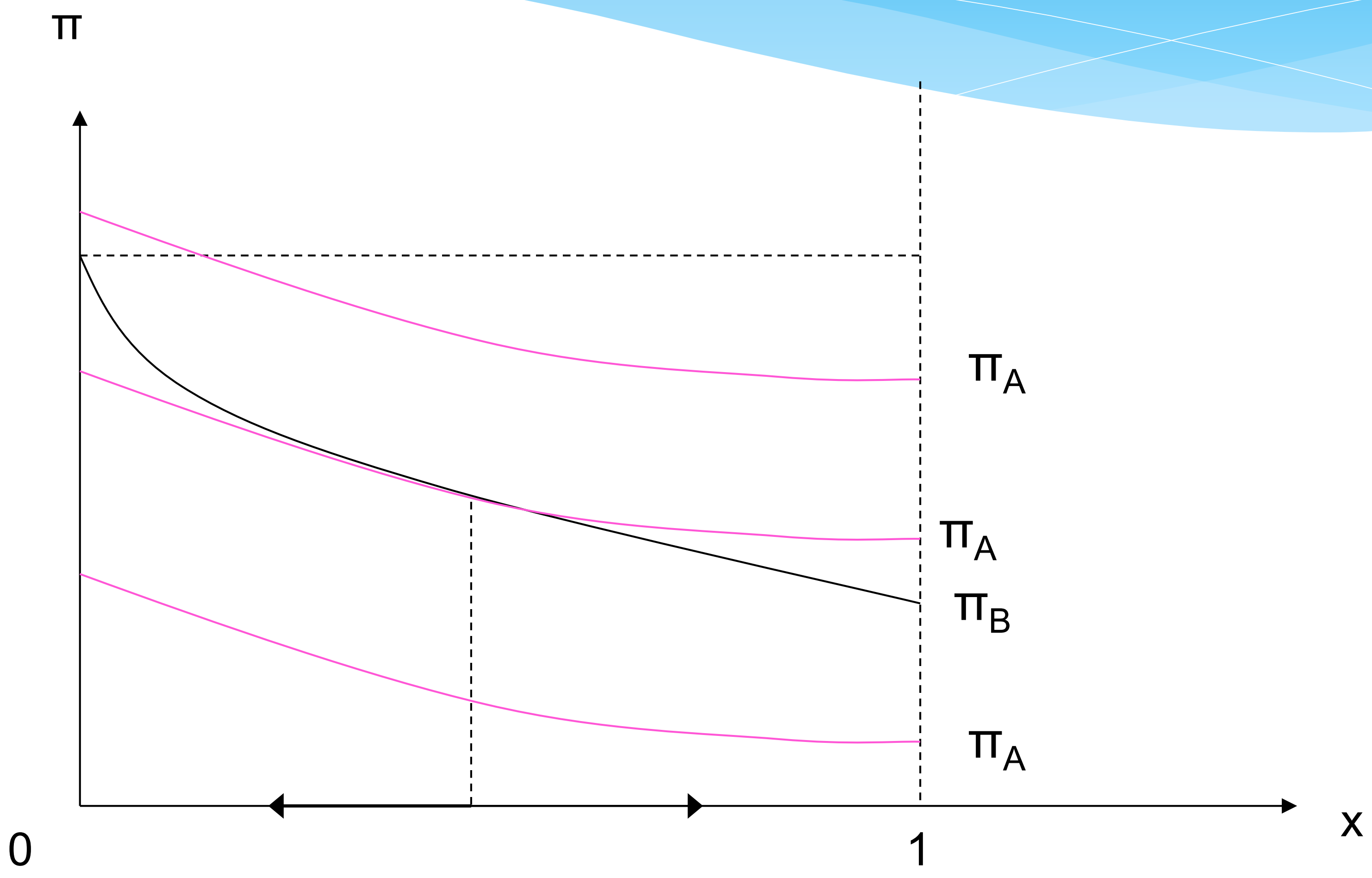
SET UP OF THE MODEL

* $W_A(x) = \bar{W}_A - \alpha x \bar{N} - \beta(1-x)\bar{N}$ where: $\alpha > \beta > 0$
* $W_B(x) = \bar{W}_B - \gamma x \bar{N} - \delta(1-x)\bar{N}$ where: $\gamma > \delta > 0$
* $\pi_i[W_i(x)]$: payoff of an agent working in i=A,B
* $\pi'_i[.] > 0$: payoffs strictly increasing functions of available water resources
* 2 possible cases: $\pi_A[W_A(x)]$ decreases more or less rapidly than $\pi_B[W_B(x)]$ as x increases.
* Pricing mechanism: water either free (p=0) or priced as follows:
* $p = \bar{p} + \mu x \bar{N}$ $\quad where: \bar{p} \geq 0, \mu \geq 0$

Replicator dynamics
(Weibull, 1995)

- $\dot{x} = x(1 - x)\{\pi_A[W_A(x)] - \pi_B[W_B(x)]\}$
- Agents move towards the most profitable sector (i.e. that has the highest payoff)
- Possible steady states:
  - Extreme equilibria: x=0, x=1
  - Inner equilibrium: 0<x<1 s.t. $\pi_A[W_A(x)] = \pi_B[W_B(x)]$

Scenario 1: payoff in A decreases less rapidly than in B



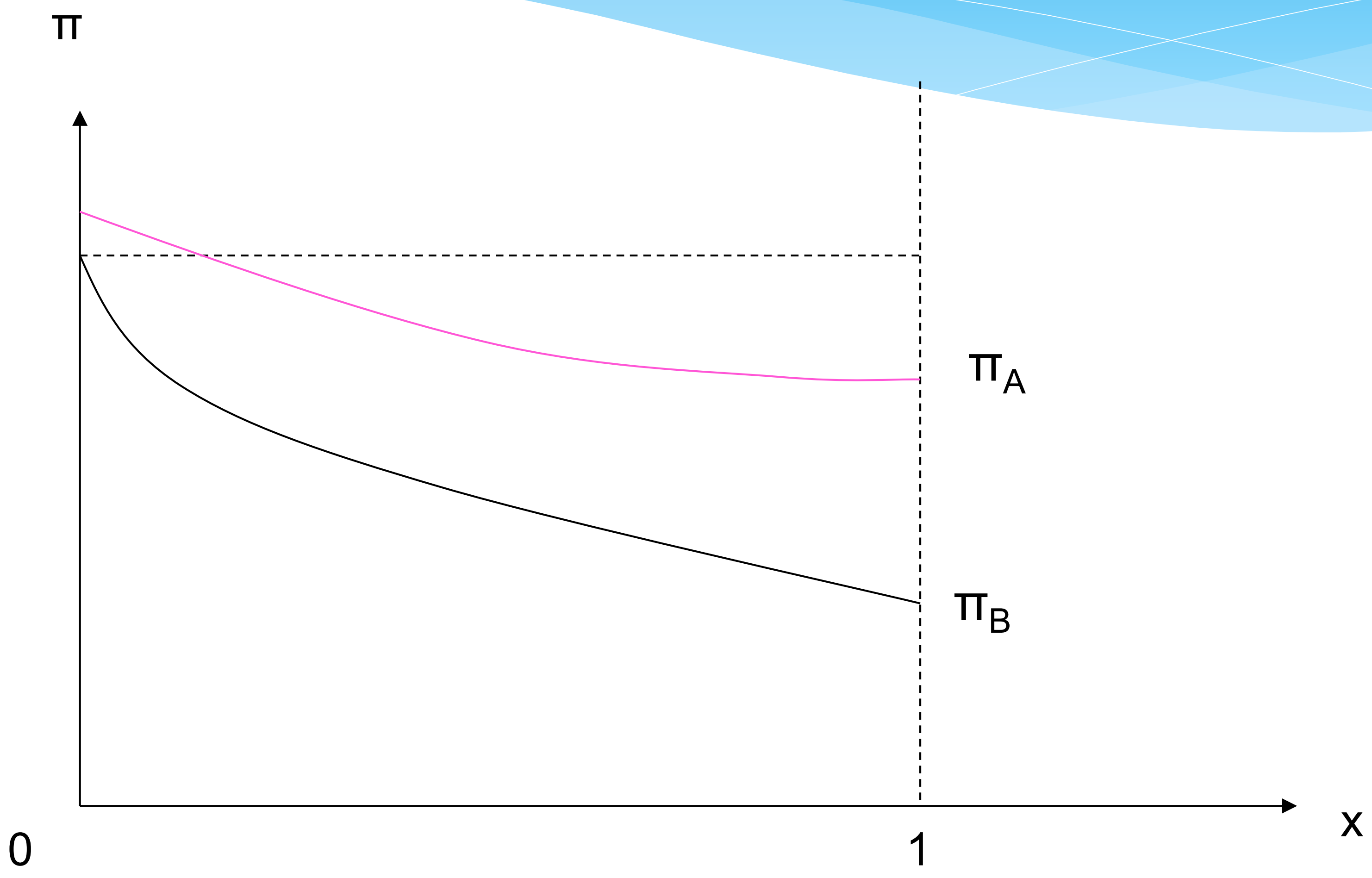
Scenario 1: payoff in A decreases less rapidly than in B

* 3 possible sub-cases:
  * 1.1) $\pi_A(x)$ always above $\pi_B(x) \rightarrow x=1$ (full specialization in A)
  * 1.2) $\pi_A(x)$ always below $\pi_B(x) \rightarrow x=0$ (full specialization in B)
  * 1.3) Curves $\pi_A(x)$ and $\pi_B(x)$ cross in the (x,π) plane at some $x^* \in (0,1)$

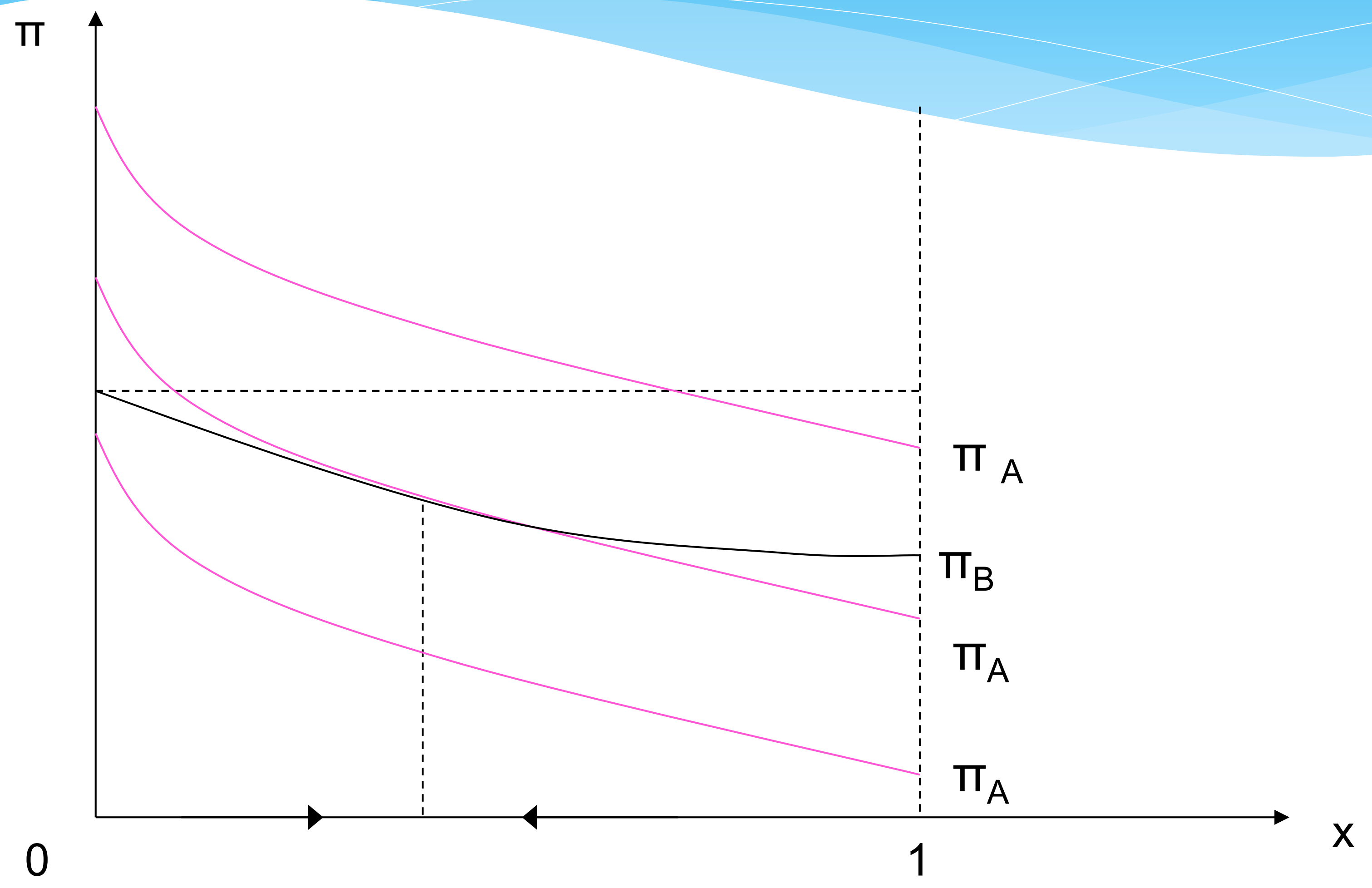
    $\rightarrow$ "bistable dynamics": if the initial share *x* of agents working in A is below the threshold level, then all agents will work in B at the end of the day; vice-versa, if is larger than the threshold level (path-dependency)

    If $\pi_B(0) > \pi_A(1)$, the individually rational choice of moving to A produces a socially undesirable equilibrium at the aggregate level for the community as a whole $\rightarrow$ Pareto-dominated stable Nash equilibrium

Scenario 1: payoff in A decreases less rapidly than in B



Scenario 2: payoff in A decreases more rapidly than in B



Scenario 2: payoff in A decreases more rapidly than in B

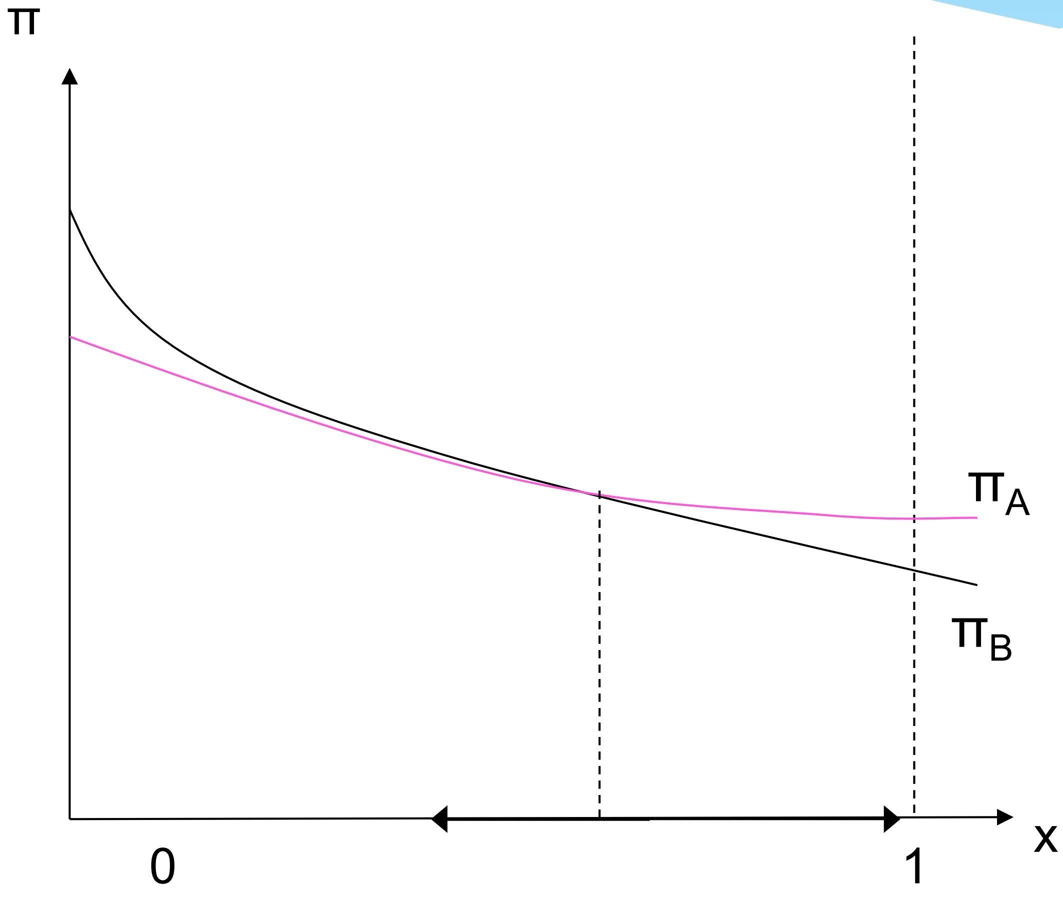
* 3 possible sub-cases:
  * 2.1) $\pi_A(x)$ steeper than $\pi_B(x)$ but it always remains above it ⟶ **x=1**
  * 2.2) $\pi_A(x)$ steeper than $\pi_B(x)$ and lies always below it ⟶ **x=0**
  * 2.3) $\pi_A(x)$ steeper than $\pi_B(x)$ and curves cross in the (x, π) plane ⟶ converge towards **the stable Nash equilibrium x*ϵ(0,1)**

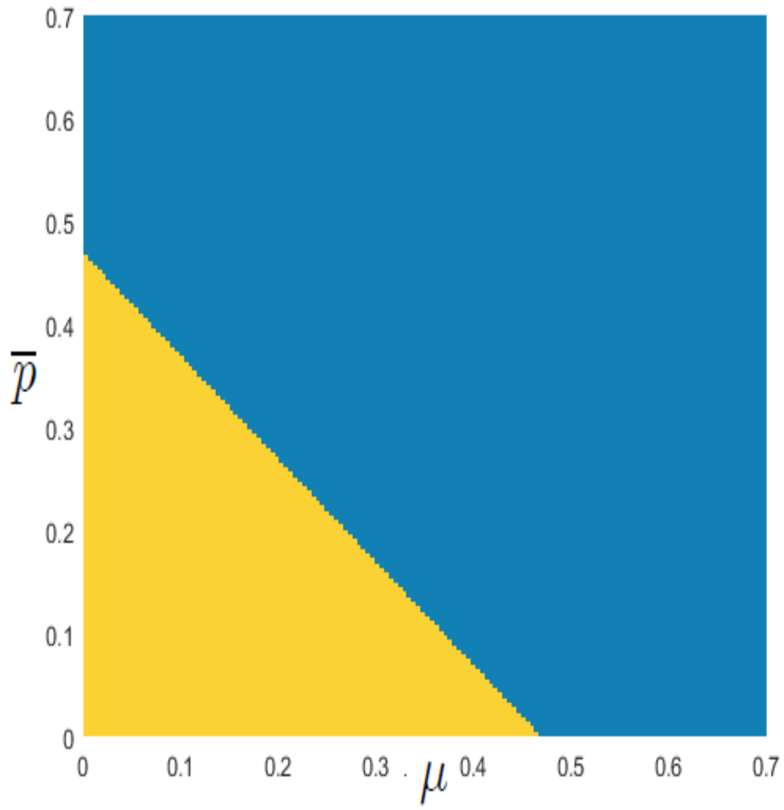
    $\pi_B(0) > \pi_i(x^*)$: although everyone would be better-off working in the lower-impact sector B, the dynamics that emerge from the strategy adoption process leads away from x=0 towards the stable equilibrium x*, so that when x<x* **the community moves along a Pareto-dominated path.**

Pricing water

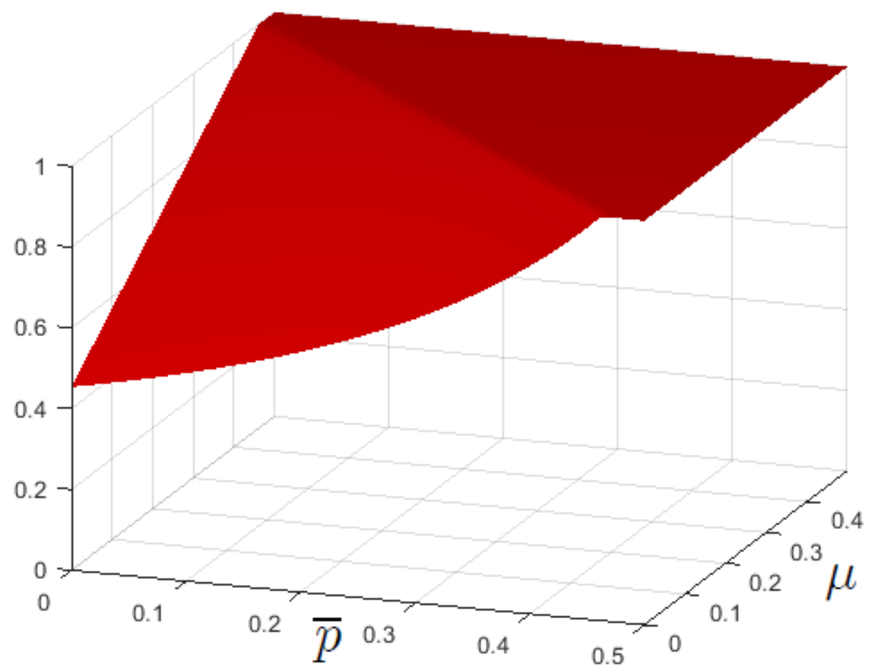
* $p = \bar{p} + \mu x \bar{N} \qquad where\ \bar{p} \geq 0, \bar{N} \geq 0$
* $\mu =$ elasticity of water price to demand (e.g. WTP)
* $\bar{p} =$ lower bound (e.g. price floor in an ETS)
* By properly modifying $\bar{p}$ and μ the Public Authority can affect the relative position of the curves and the dynamics of the system (and thus avoid Pareto-dominated outcomes)
* Fix $\bar{p}$ and μ so as to ensure that the curve π_A lies always below π_B:
* $\pi_A(W_A(x)) - \bar{p} + \mu x \bar{N} < \pi_B(W_A(x))$
* Results can hold as long as $p_A > p_B$

Simulation results-1: from bistability (yellow) to unique equilibrium x=0 (blue)





Simulation results-2: the separating threshold



Concluding remarks

* Water crucial for production processes but limited → water conflicts/competition among individuals, sectors, countries…
* The present paper examines a 2-sector model of water competition with imitative behaviours across agents
* If water is unpriced, the society as a whole may end up in a "poverty trap": individually rational choices lead to full/partial specialization in the most water-consuming (polluting) sector, but agents would be better-off by working in the alternative ("cleaner") sector.
* Water pricing mechanism to "escape" the poverty trap
* A properly designed WTAR (WTPR) [e.g. a sufficiently high price floor] can drive the economy away from the Pareto-dominated equilibrium

Agenda for the future

1. Introduce Leontieff production functions: e.g. YA=min[aWA,bxN]
2. Intertemporal evolution of water resources (e.g. role of infrastructures such as dams, canalizations etc…) $\longrightarrow$ from unidimensional to bidimensional dynamics (Phase plan in *x* and *W*)
3. Extend water competition from within countries to across countries

Thank you for your attention!!

simone.borghesi@unisi.it