UF | UNIVERSITY of FLORIDA
Institute of Food and Agricultural Sciences
Agricultural and Biological Engineering Department

NSF

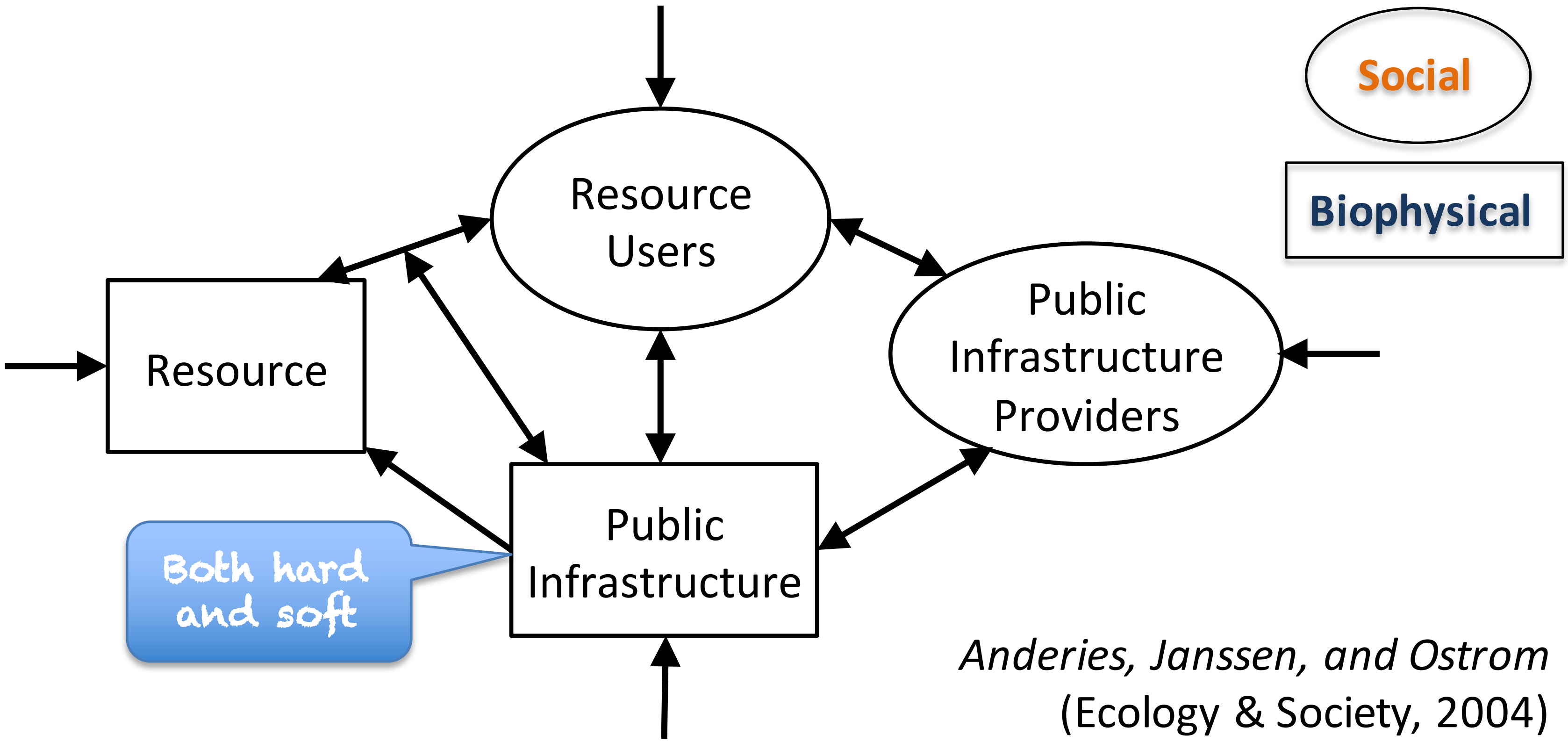
A Modeling Framework for Coupled Natural-Human Systems

Rachata Muneepeerakul
Agricultural and Biological Engineering
University of Florida
rmuneepe@ufl.edu
In collaboration with J. Marty Anderies
(School of Sustainability, Arizona State University)

3 December 2015

NSF EPSCoR, Norman, OK

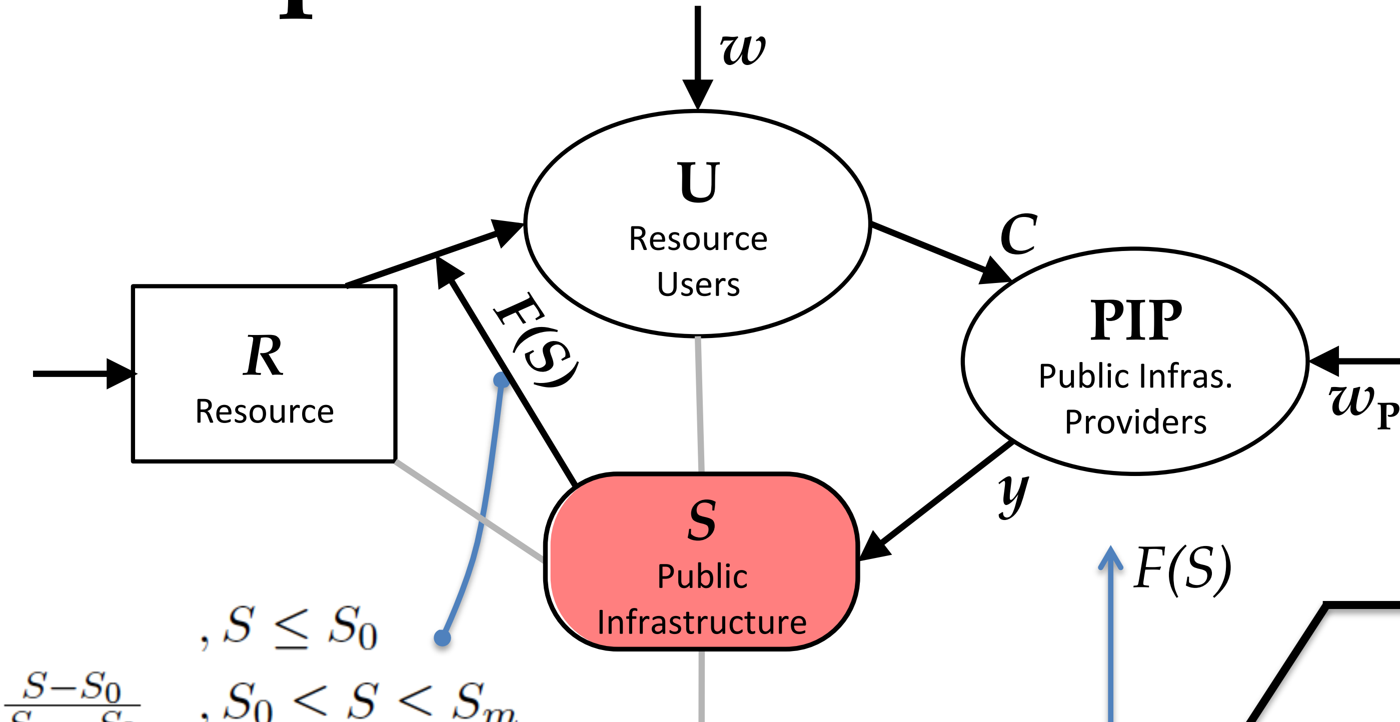
Conceptual framework



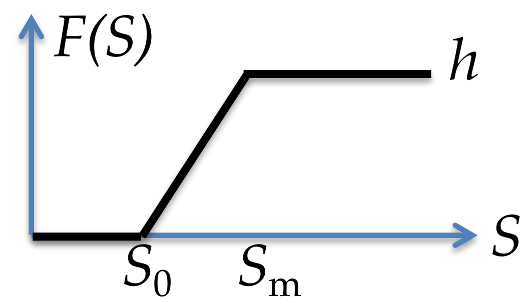
Anderies, Janssen, and Ostrom
(Ecology & Society, 2004)

Goal: Develop a unified theory of coupled natural-human systems
Approach: Systematically and mathematically operationalize the above conceptual framework

State of public infrastructure (S)



$$F(S) = \begin{cases} 0 & , S \le S_0 \\ h\frac{S-S_0}{S_m-S_0} & , S_0 \le S \le S_m \\ h & , S > S_m \end{cases}$$

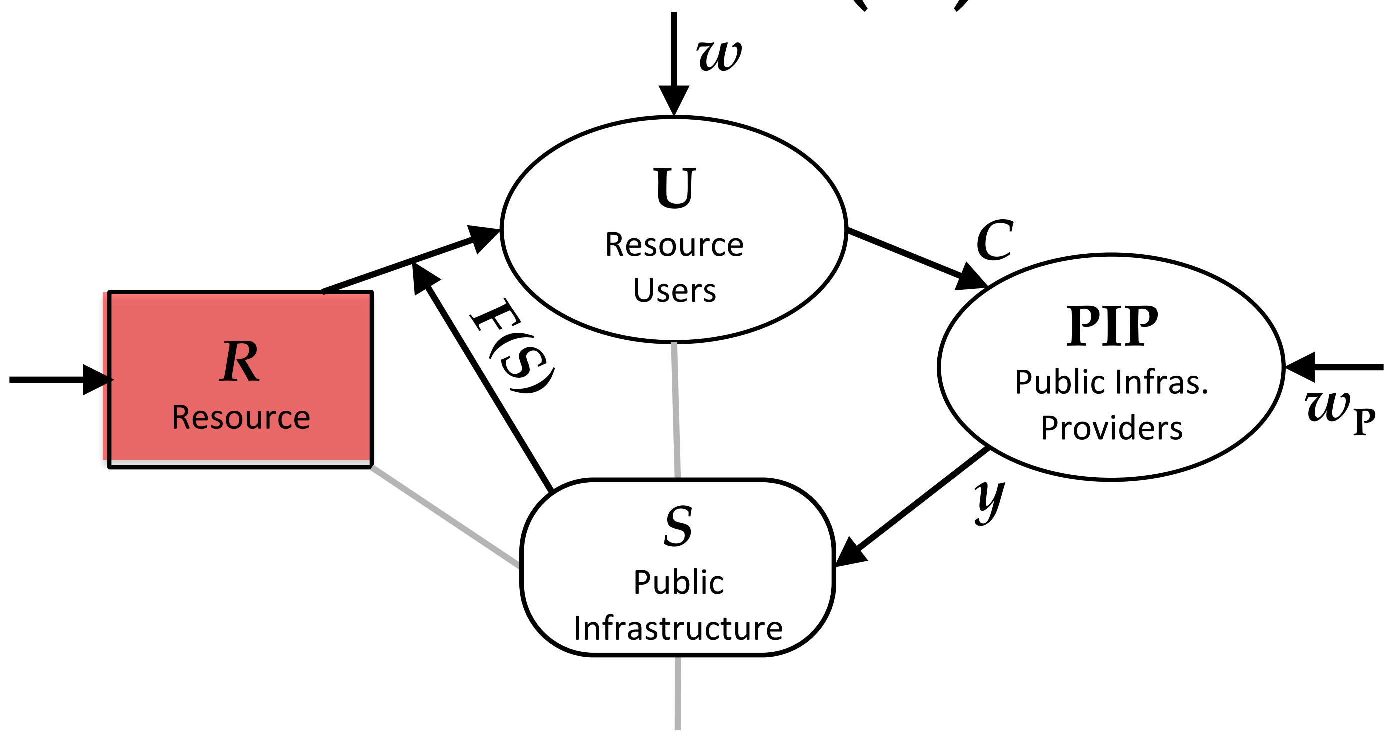


- ✓ Threshold behavior in its capacity—requires collective action
- ✓ Constant depreciation/decay—eventually collapses without maintenance

Maintenance Decay

$$\frac{dS}{dt} = M(\ldots) - \delta S,$$

Resource (R)



Usage rate

$$\frac{dR}{dt} = I - lR - UNF(S)R$$

Natural inflow

Natural loss (e.g., ET, seepage)

Extraction by humans through infrastructure

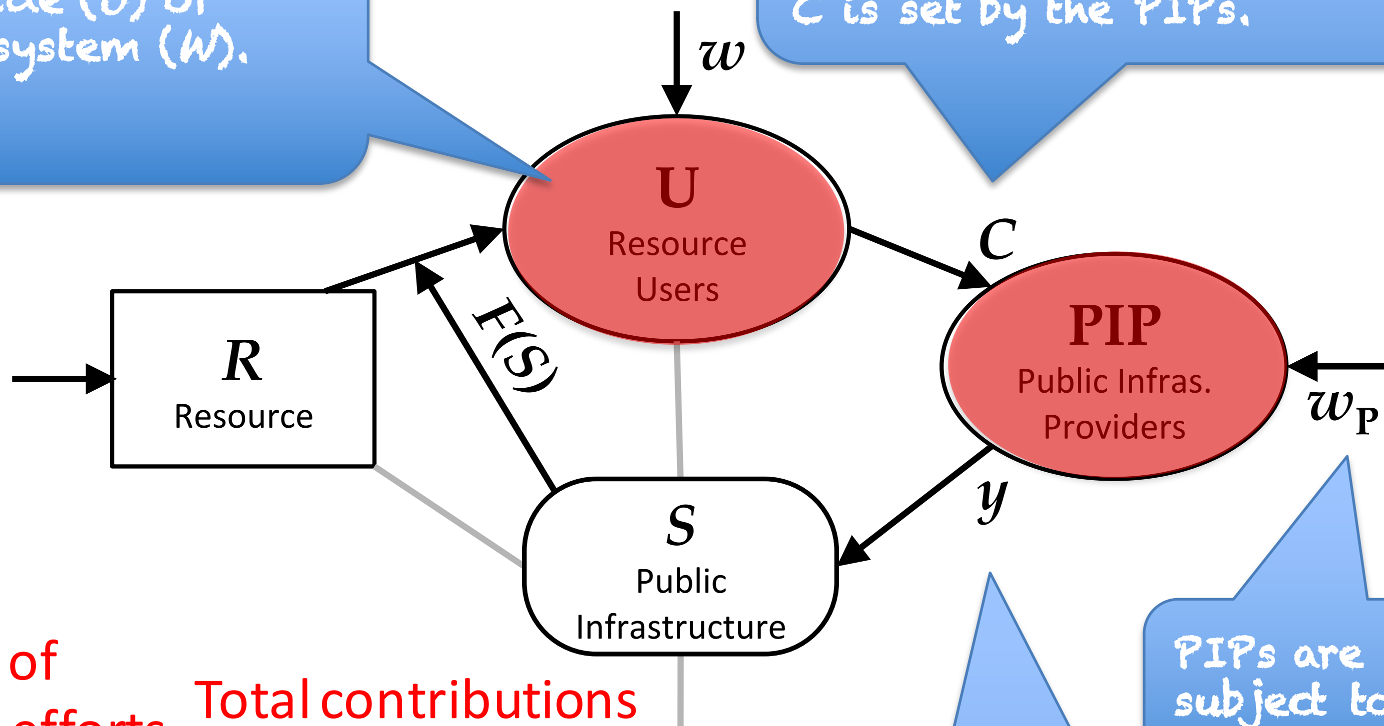
Two types of social actors: U and PIP

Users have 2 strategies: working inside (U) or outside the system (W).

$U + W = 1.$

Users must contribute a fraction C of the income they make from the infrastructure system to the PIPs.

C is set by the PIPs.



PIPs are also subject to outside incentives.

PIPs spend a fraction y to maintain the public infrastructure.

Effectiveness of maintenance efforts

Total contributions from users to PIP

$$\frac{dS}{dt} = \mu' y CaRF(S)UN - \delta S$$

Fraction invested in maintenance

Part self-organized, part designed

the challenge, regardless of the choice of analytical technology remains: How do we construct a version of (12–15) with the *right* level of complexity that is useful for development of policy that respects the fact that SES are partially self-organizing and partially designed.

(**SES** = social-ecological systems)

(*Anderies*, Bull Math Biol 2015)

Replication (social learning)	Optimization
Boundedly rational	Rational
Myopic	Long-term
Self-organization	Design/planning

Self-organizing Users *vs.* Optimizing PIP

Users self-organize through social learning (replicator dynamics):

$$\pi_U = (1 - C)aRh$$

$$\frac{dU}{dt} = rU(1-U)(\pi_{\mathrm{U}} - w)$$

U increases when working inside pays better than working outside.

It would increase fast if there are already a lot of existing adopters (U) and potential replicators (1–U).

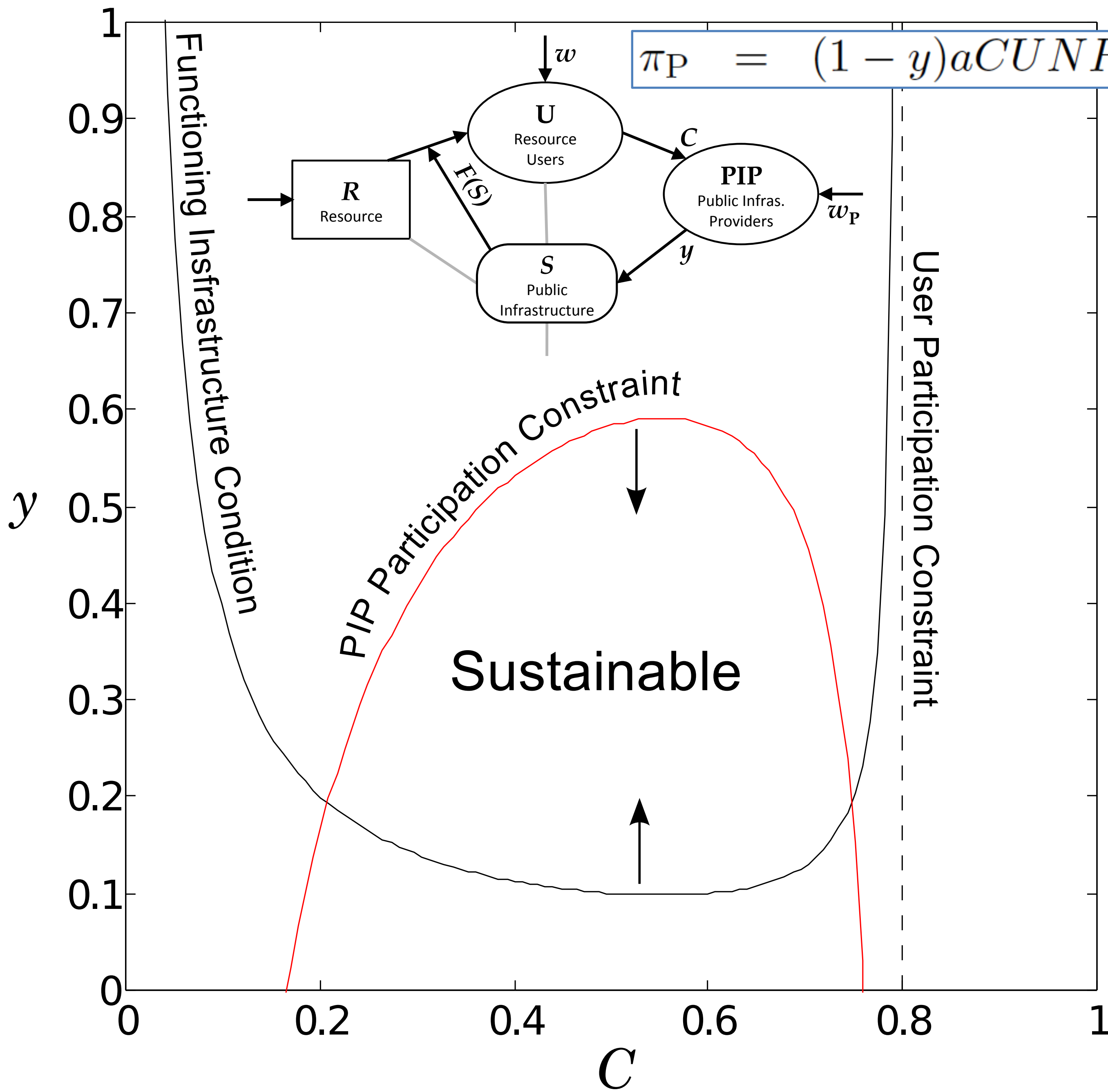
PIP optimizes its payoff:

$$\pi_{\mathrm{P}} = (1 - y)aCUNRF(S)$$

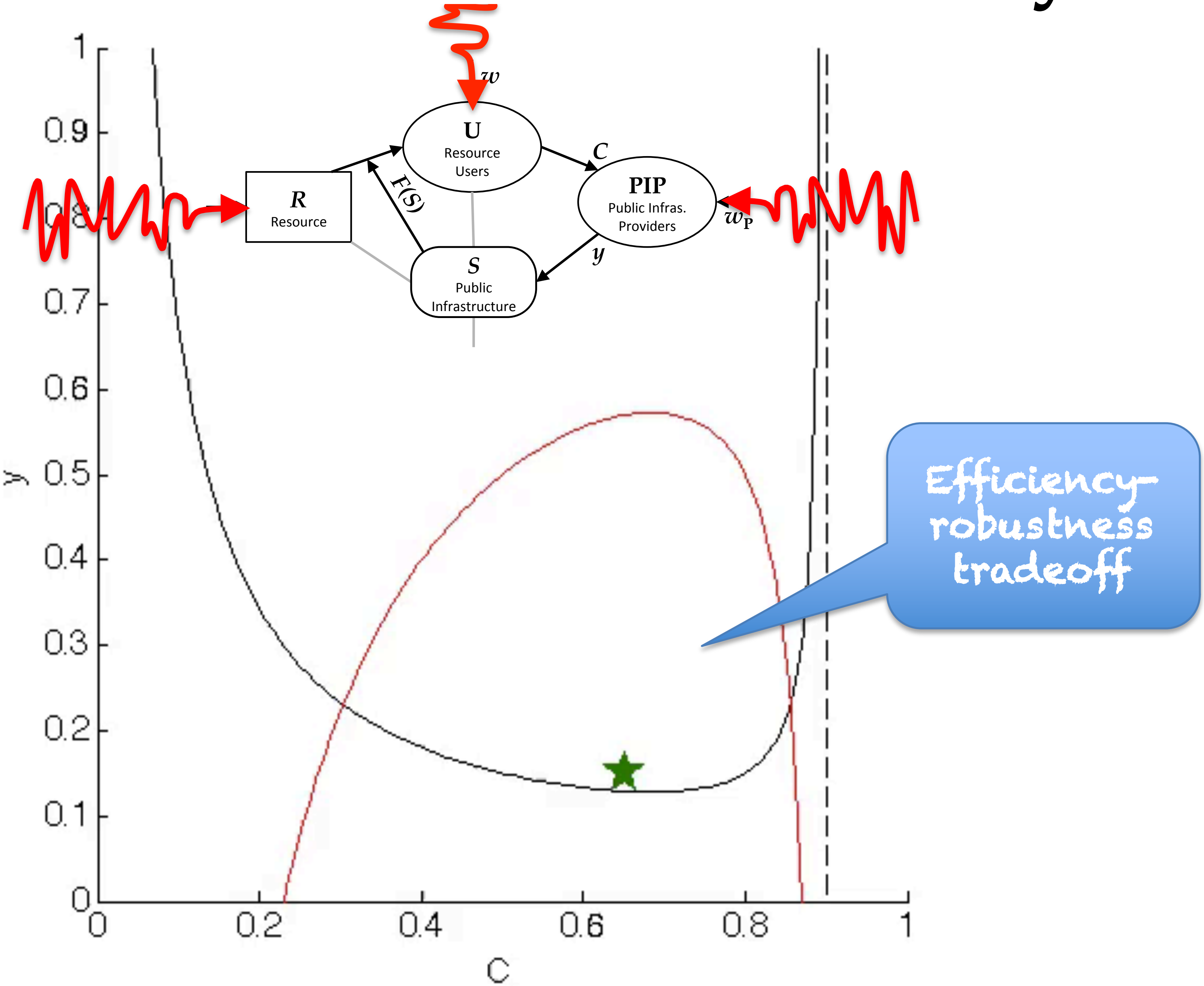
PIP attempts to maximize their payoff by selecting C and y. But the users self-organize to respond to those "policies," which in turn affect the infrastructure functionality and resource availability.

PIP's *C*-*y* decision space

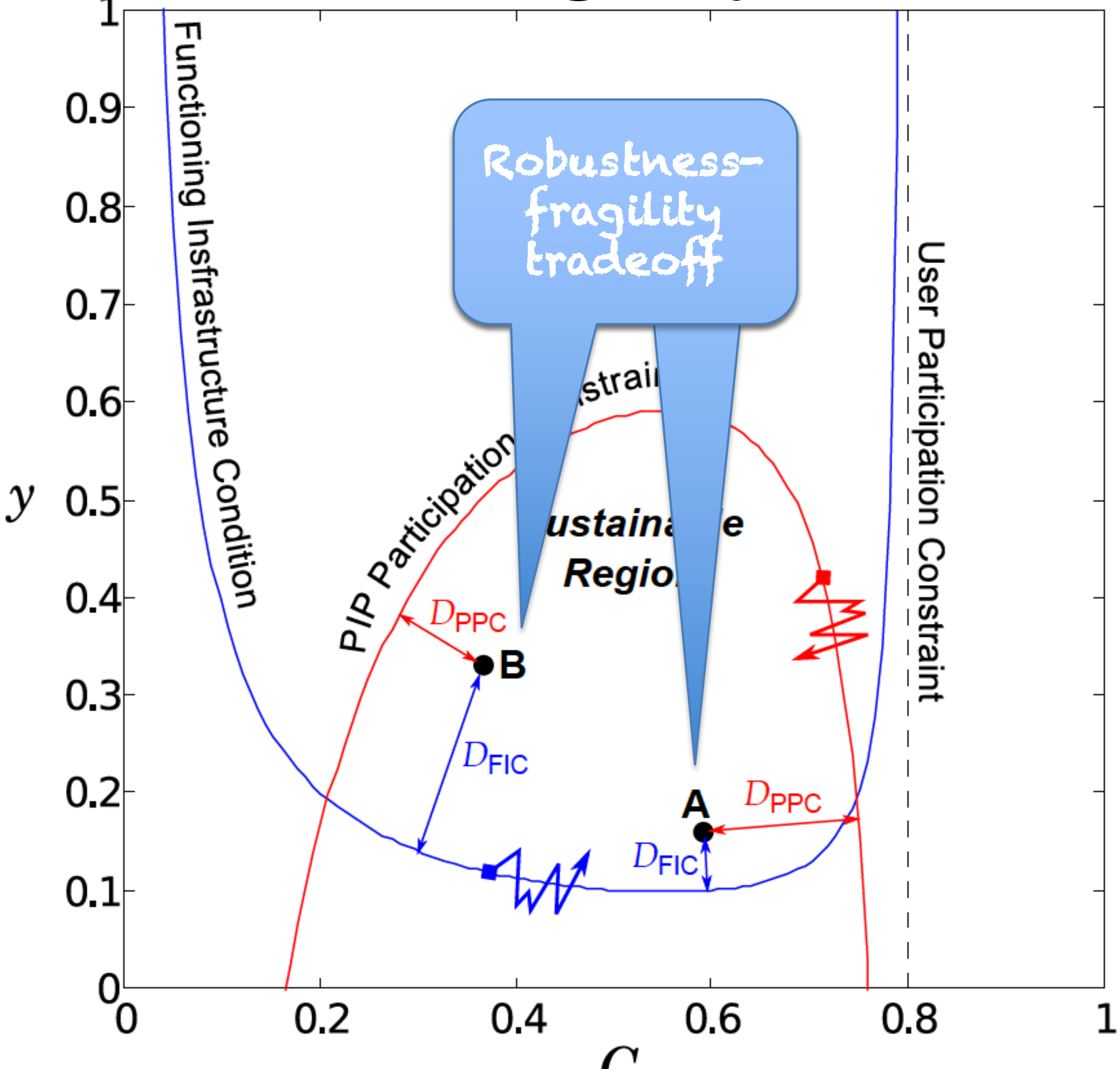
$$\pi_P = (1-y)aCUNRF(S)$$



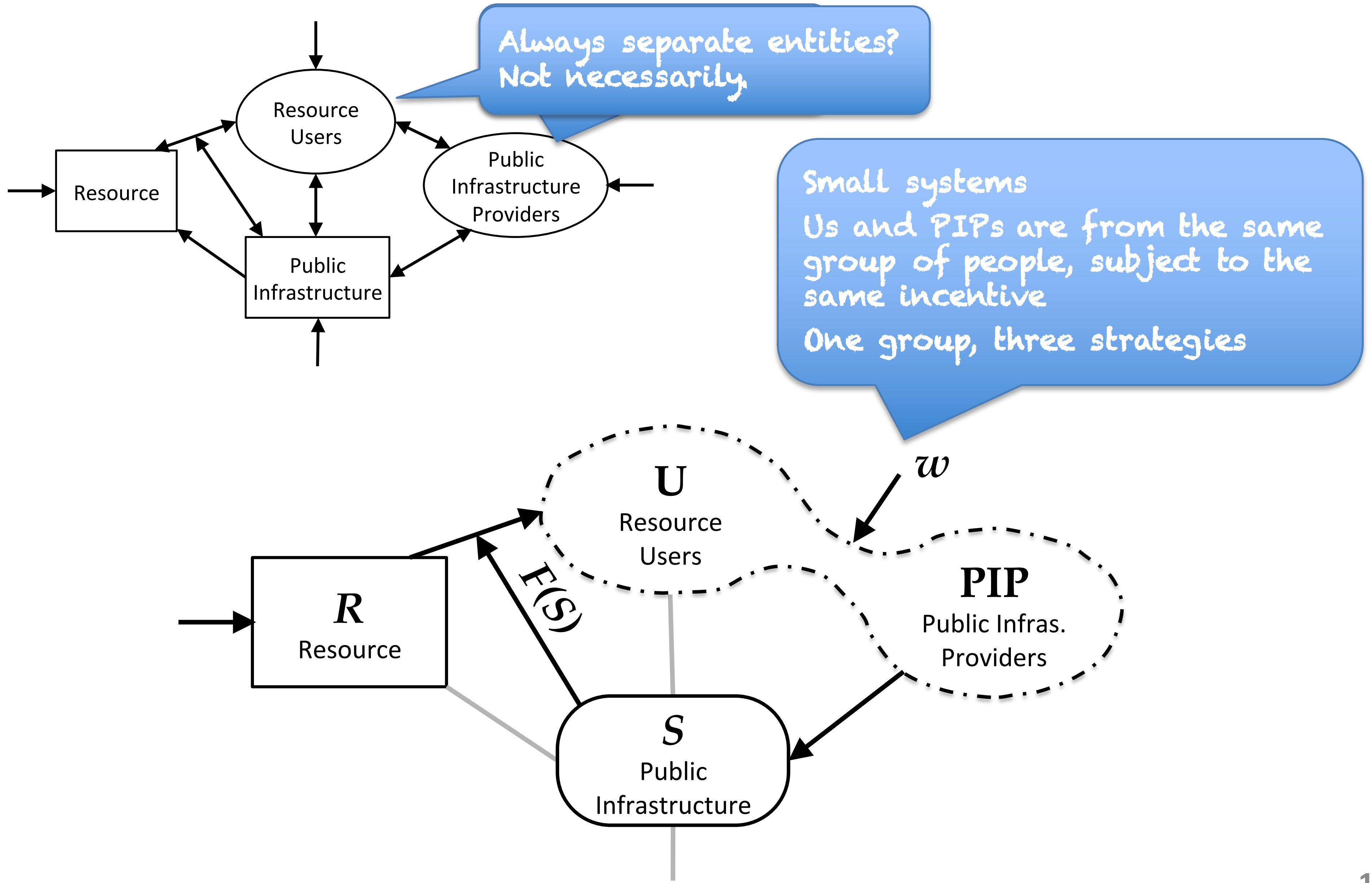
Possible extension: variability



Robustness-fragility tradeoffs



Different social structure



UF UNIVERSITY of FLORIDA
Institute of Food and Agricultural Sciences
Agricultural and Biological Engineering Department

Summary

Resource, humans, & infrastructure, systematically combined;
Interplays & dilemmas, mathematically defined.
These systems are both designed and self-organized;
With optimization & replication, they could be characterized.
In a clear, simple model, constraints are made unambiguous;
Important lessons are then brought to focus.
Too much emphasis on performance and certain robustness,
The system might be fragile against other stresses.
With some key dynamics on a sound mathematical ground,
Interesting questions and extensions abound.
User diversity, resource variability, and other complexity…
There is a lot of work we can expect to see.

Thank you for your attention.