Understanding Common-Pool Resource Problems in Infrastructures: Exploring Analogies with Natural Resource Systems

Pieter Bots and Rolf Künneke

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Outline of this presentation

• Common Pool Resource (CPR) problems
• Significance of CPR problems related to infrastructures
• A “diagnostic approach” proposed by Ostrom (2007)
• Applicability of this approach to infrastructures
• Discussion: research potential of this approach
Common pool resource (CPR)

“A natural or man-made resource system that is sufficiently large to make it costly (but not impossible) to exclude potential beneficiaries from obtaining benefits from its use.” (Ostrom 1990)

<table>
<thead>
<tr>
<th>Use</th>
<th>Accessibility</th>
<th>Accessibility</th>
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<tbody>
<tr>
<td>Rival</td>
<td><strong>Private goods</strong></td>
<td><strong>Common Pool Resources</strong></td>
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<tr>
<td>Non rival</td>
<td>Club goods</td>
<td>Collective (Public) goods</td>
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“free riders”, overuse, “tragedy of the commons”
“Governing the commons”

What institutions are appropriate to mitigate CPR problems?

- No simple answers:
  - complex and unpredictable behavior
  - multiple causalities
  - non-linearity
  - cross-scale in time and space
  - evolutionary

- No panaceas (e.g., “privatization”, “government ownership”)
  - these “solutions” are too general; every case is unique

Learn from analysis and comparison of numerous case studies
Research on CPR

- Focus on social-ecological systems
  - river basins, lake systems, forests
- Focus on rules
  - Institutional Analysis and Development (IAD) framework
- Focus on self-organization
  - institutions as emergent system properties

1 see the Digital Library of the Commons at http://dlc.dlib.indiana.edu/

Infrastructures

Power grids

Rail networks

Common Pool Resource problems in Infrastructures
Common Pool Resource problems in Infrastructures
Infrastructures as CPR

Non-excludable resources, because:

• difficult to monitor and control access
  • complex networks with numerous access points
  • spread across large geographical areas

• politically motivated universal service obligations
  • infrastructures provide essential services

• difficult / impossible to determine who appropriates what services
  • usage difficult to monitor at the individual level
  • systemic services cannot be assigned to individual users
    (traffic control, load balancing, quality control, …)
CPR problems in infrastructures

- Crowding effects and overuse problems:
  - network congestion
  - insufficient reliability and robustness
  - insufficient sustainability
  - lack of investment

- “Simple solutions” like government ownership are neither possible nor appropriate (any more) because of:
  - internationalization
  - commercialization
  - convergence
  - technical innovation
  - changing social expectations
Ostrom’s “diagnostic approach”

- Inspired by the diagnostic approach used in medicine:
  - although each case might be unique, what are the shared attributes or variables?
- Three aspects to be considered:
  - partitioning of variables into classes and sub-classes
  - identification of separable sub-systems that are relatively independent from each other
  - identification of synergies between subsystems
A multi-tier analytical framework

Social, Economic, and Political Settings (S)

Resource System (RS)

Interactions (I) → Outcomes (O)

Governance System (GS)

Resource Units (RU)

Users (U)

Related Ecosystems (ECO)

Direct causal link

Feedback

Purpose of the framework

Enable researchers to develop cumulative, coherent, and empirically supported answers to three broad questions:

1. What patterns of interactions and outcomes are likely to result from a particular configuration in a specific environment?

2. What is the likely endogenous development of different governance arrangements, use patterns, and outcomes with or without external financial inducements or imposed rules?

3. How robust is a particular configuration to external and internal disturbances?

set of rules for the governance, ownership, and use of a resource system and specific resource units

technological, socioeconomic, and political
# Second-tier variable categories

<table>
<thead>
<tr>
<th>Social, Economic, and Political Settings (S)</th>
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<tbody>
<tr>
<td>S1- Economic development. S2- Demographic trends. S3- Political stability.</td>
</tr>
<tr>
<td>S4- Government settlement policies. S5- Market incentives. S6- Media organization.</td>
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<td>RS2- Clarity of system boundaries</td>
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<td>RS3- Size of resource system</td>
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<tr>
<td>RS4- Human-constructed facilities</td>
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<tr>
<td>RS5- Productivity of system</td>
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<tr>
<td>RS6- Equilibrium properties</td>
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<tr>
<td>RS7- Predictability of system dynamics</td>
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<td>RS8- Storage characteristics</td>
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<td>RS9- Location</td>
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<td>GS3- Network structure</td>
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<td>RU3- Interaction among resource units</td>
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<td>RU4- Economic value</td>
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<td>RU5- Size</td>
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<td>RU6- Distinctive markings</td>
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<td>RU7- Spatial &amp; temporal distribution</td>
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<th>Users (U)</th>
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<td>U2- Socioeconomic attributes of users</td>
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<td>U3- History of use</td>
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<td>U4- Location</td>
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<td>U5- Leadership/entrepreneurship</td>
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<td>U6- Norms/social capital</td>
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<td>U7- Knowledge of SES/mental models</td>
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<td>U8- Dependence on resource</td>
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<td>U9- Technology used</td>
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<td>I2- Information sharing among users</td>
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<td>I3- Deliberation processes</td>
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<td>I4- Conflicts among users</td>
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<td>O1- Social performance measures</td>
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<td>O2- Ecological performance measures</td>
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<td>(e.g., overharvested, resilience, diversity)</td>
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<td>O3- Externalities to other SESs</td>
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<td>ECO1- Climate patterns.</td>
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<td>ECO2- Pollution patterns.</td>
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<tr>
<td>ECO3- Flows into and out of focal SES.</td>
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Applicability to infrastructures (1)

**Governance System (GS)**
- GS1 - Government organizations
- GS2 - Non-government organizations
- GS3 - Network structure
- GS4 - Property-rights systems
- GS5 - Operational rules
- GS6 - Collective-choice rules
- GS7 - Constitutional rules
- GS8 - Monitoring & sanctioning processes

**Typical examples:**
- Monopolistic competition
- Access competition
- Network competition

**Social network!**

**Note:**
the IAD framework provides more detailed rule categories
Applicability to infrastructures (2)

- “senders” or “receivers” (or both) of what is transported
- part of what is transported

Note:
variety in these variables is equally large for SES

Users (U)

- Number of users (U1)
- Socioeconomic attributes of users (U2)
- History of use (U3)
- Location (U4)
- Leadership/entrepreneurship (U5)
- Norms/social capital (U6)
- Knowledge of SES/mental models (U7)
- Dependence on resource (U8)
- Technology used (U9)

- rail: low (railroad companies)
- road: huge (cars)
- power, gas, water: varies by type (few producers, many consumers)

- depends on sector
- complex key variable!
Applicability to infrastructures (3)

- water, electrical power, oil, gas, cars, trains, information

Resource System (RS)
- RS1: Sector (e.g., water, forests, pasture, fish)
- RS2: Clarity of system boundaries
- RS3: Size of resource system
- RS4: Human-constructed facilities
- RS5: Productivity of system
- RS6: Equilibrium properties
- RS7: Predictability of system dynamics
- RS8: Storage characteristics
- RS9: Location

FOCAL, yet underspecified!

key variables

Note:
- Dynamic behavior of engineered systems is often better understood than that of ecosystems

what does infrastructure “produce”?
Applicability to infrastructures (4)

Resource Units (RU)
- RU1: Resource unit mobility
- RU2: Growth or replacement rate
- RU3: Interaction among resource units
- RU4: Economic value
- RU5: Size
- RU6: Distinctive markings
- RU7: Spatial & temporal distribution

Note:
It is difficult to apply this concept
- RU = transport service?
- RU = time slot?
- RU = flow through network?
- RU = edge/node/path in network?
Applicability to infrastructures (5)

**Interactions (I)**

I1. Harvesting levels of diverse users  
I2. Information sharing among users  
I3. Deliberation processes  
I4. Conflicts among users  
I5. Investment activities  
I6. Lobbying activities

all these are relevant
Applicability to infrastructures (6)

**Outcomes (O)**

O1- Social performance measures  
    (e.g., efficiency, equity, accountability)
O2- Ecological performance measures  
    (e.g., overharvested, resilience, diversity)
O3- Externalities to other SESs

*only the term may not be appropriate for infrastructures*
Preliminary conclusion

• The analytical framework is useful...
  • covers a great many relevant characteristics of infrastructures
  • raises numerous questions
  • provides a meaningful structure for empirical research
• but...
  • Resource System category is underspecified
  • Resource Units category is not easy to map
  • second-tier variables are still very generic
Speculation

- Multi-tier framework can develop into an **ontology** for infrastructures
- Research into governance of infrastructures can benefit from such ontology development:
  - Disambiguated vocabulary for reporting case studies enables systematic cross-case comparison
  - Pooling data obtained in case studies enables “large-N studies”
- CPR concepts & theories may not apply:
  - Evolution of detailed and intricate cultural regimes around, e.g., lakes or pastures differs from evolution of capacity management regimes for large scale infrastructures