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Institutions and the Performance of Coupled Infrastructure Systems: Insights from Large-N Studies of Ostrom's Institutional Design Principles

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Introduction

Some of the most challenging problems that modern societies face involve social dilemmas related to natural resources and the environment. Readers of this journal will be intimately familiar with the notion of social dilemmas, indirectly referenced in the journal title through the word "commons". Many scholars have worked for decades to understand what characteristics of social organization enable groups to solve social dilemmas. Social dilemmas involve two problems 1) individuals face a choice in which the best outcome can only be achieved if many other decision makers make a choice that benefits the total payoff of the group and 2) there is no way to guarantee others will also make decisions that will benefit the group, so individuals face strong incentives to make a choice that is best for themselves and will have negative impacts on the group. Solving these two problems has proven to be devilishly difficult as Hardin (1968) reminded the (academic) world almost 50 years ago. Again, as readers of this journal know, the dominant discourse around social dilemmas at the time of Hardin's article and the subsequent 20 years suggested that their solution required the intervention of an exogenous governance body that either a) directly restricts choices of actors thus removing challenge 2 of social dilemmas or b) establishes and enforces property rights removing challenge 1. Of course, these two solutions are just different sides of the same theoretical coin, differentiated by an arbitrary choice about the assignment of "property rights".

Solutions based on one of these two options has dominated the policy discourse and policy action spaces in developed countries for at least five decades. If anything, attempts at implementing these solutions have demonstrated that the devil is in the (practical implementation) details. Critiques of these solutions often involve discourses about very specific circumstances that either enabled or prevented the success of regulatory- or property-rights-based policy interventions. E. Ostrom has referred to this singular focus on rather general ideas for governing social dilemmas as panacea thinking, and has called for the academics and practitioners alike to move beyond it (Ostrom et al., 2007; Ostrom, 2010) and has proposed a framework for doing so (Ostrom, 2007).

The study of hundreds of case studies by commons scholars has provided many examples of communities that have been able to solve social dilemmas in common pool resource (CPR) contexts, many inspired by the seminal work of Ostrom (1990). A key challenge scholars face going forward

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is to identify structure within the whole range of endogenously generated and enforced institutional arrangements capable of governing CPRs. With "institutional arrangements" we refer to clusters of rules, assembled from any number of individual rules based on building blocks frrom seven rule classes Ostrom et al. (1994) that specify what actions are allowed or required, what information is accessible, and how costs and benefits are attached to actions and outcomes. A moment's thought will reveal to the reader the enormous number of possible institutional arrangements. Ostrom made a huge effort, through her comparison of hundreds of case studies from irrigation, forestry, fisheries, and ground water systems, to give some meaningful structure to the huge variation institutional arrangements possible in theory and observed in practice. Through comparative analysis, Ostrom developed 8 *design principles*, familiar to readers of this journal, that describe broad features of rule clusters associated with successful CPR governance regimes and, thus, form a basis for assembling rule clusters (i.e. *designing* institutions) capable of helping solve social dilemmas in CPR contexts. Ostrom later regretted to use the term design principles since they were hypotheses emerging from case studies rather than blue prints for how to govern the commons (Ostrom et al., 2007).

As a political scientist, Ostrom's work on the governance of common pool resources was squarely focused in the social and institutional domain. Broadly speaking, this work relied on the notion that solving social dilemmas required getting the institutions right, or achieving a good "fit" of institutions to a given social and environmental context. In Ostrom's design principles, the metric for "right" and "good fit" is whether institutions enable successful *collective action* to address social dilemmas. More specifically, Ostrom refers to them as design principles "for long enduring common property institutions." More broadly, they are one way of making sense out of the institutional diversity she observed, and we have used the Design Principles as the foundation for the work presented in this special feature.

A key challenge for scholars of CPR's and of social dilemma's more generally is to build a stronger empirical and theoretical basis for the Design Principles using a systematic methodology that can be robustly replicated. It turns out that this is an extremely difficult task for both practical and theoretical reasons. The formost practical constraint is the shear magnitude of the task of systematically extracting data associated with complex social-ecological systems. Second is the challenge of developing a robustly replicable methodology to "code" the cases. Given these challenges, it is not surprising that beyond Ostrom's large-N comparative analysis conducted to develop the Design Principles, there have been very few studies to systematically test the design principles 'out of sample'. There are several interesting examples in which scholars search for the occurrence of particular instantiations of the Design Principles in particular contexts such as irrigation in Nepal (Ostrom and Benjamin, 1993), agro-pastoralism in Tanzania (Quinn et al., 2007), and forestry cooperatives in Peru (Morrow and Hull, 1996). The conclusions that can be drawn from such studies are necessarily incomplete and idiosyncratic, typically illustrating that some subset of the design principles are present and one or two of those present seemed to have contributed to better governance *in a particular situation* under investigation by the authors.

Of course, such investigations are valuable sources of new knowledge and understanding but can make only limited contributions to building systematic, empirically-based theories of social dilemmas related to CPRs. As Agrawal (2001) points out, several limitations of case-study-based research must be overcome in order to move theory building forward:

- non-comparability of results from different studies due to variation in context and methodologies,
- the problem of spurious correlation such as linking the presence or absence of individual design principles to success or failure of CPR governance,

- and the difficulty of avoiding multiple and contingent causation in single case studies.

It is exactly these challenges that the papers in this special feature seek to address. Agrawal (2001) advocates careful attention to research design, index construction to reduce the number of variables in a given analysis, and a shift toward comparative rather than case study analysis. The three papers in the special feature rely on coded cases using carefully designed "indexes" in the spirit of Ostrom's CPR database. This coding based research approach is a targeted attempt to make cases comparable. Based on these indexes, Baggio et al. undertake a careful analysis, using multiple methods, of the relationship between indicators of institutional design principles and successful CPR governance. Great care is taken to attempt to avoid problems of spurious correlations and multiple causation by exploring if and how the design principles may *interact* to produce certain outcomes. Barnett et al. (this volume), by examining cases that are "outliers" really focus on contingent causation. Finally Ratajczyk et al. (this volume) dig into the challenges of developing robust indexes and robust coding protocols to measure these indexes.

Taken together, these three studies are a modest but pioneering first step in addressing some of the challenges set out by Agrawal (2001) more than a decade ago. The research in this area is nascent - the only study that attempts to systematically investigate the effectiveness of the Design Principles using large-N comparative analysis known to the authors prior to the research presented in this special feature is due to Cox et al. (2010). Naturally, to ensure comparability across cases, methodology, and researchers, the research presented in this special feature relies on the same cases used by Cox et al. (2010). The results presented in this special feature represent the continued evolution of this work, but are only a small step. The challenge for the commons research community is immense because the data points are so complex and numerous. A key point to emphasize is that a powerful *theoretical framework* exists in the Institutional Analysis and Development (IAD) framework and its various extensions discussed below. Although Poteete et al. (2010) provide some direction, what we lack as a research community is a powerful *methodological framework* to actualize theoretical frameworks to build systematic, empirically-based theories of social dilemmas related to the environment. In the remainder of this paper, we sketch theoretical and methodological frameworks that may help the commons research community move toward these goals.

From Institutional Design to Governance in Coupled Infrastructure Systems

While the IAD framework has been in use for over 30 years (e.g. at least since Kiser and Ostrom (1982)), and is probably the most commonly-used framework for thinking about institutions in social-ecological systems, there remains significant variation in how the IAD Framework is adopted in practice. The need for continued clarification and sharpening of the framework is evidenced in Ostrom's own writing. Specifically, in 2011 she wrote a review article as part of a special feature on applications of the IAD framework with the purpose of clarifying the intellectual basis of the IAD and "discuss how and why the framework itself has changed over time" (Ostrom, 2011, p. 7). One of the key changes relates to the core analytical unit of the IAD, the action situation. The papers presented in this special feature can be seen as clarifying the way different elements that constitute the action situation intermingle to produce outcomes in social-ecological systems. In the same way that the IAD framework has evolved over time based on feedback from its users, we suggest further extensions of the more recent outgrowths of the IAD such as the SES and Robustness frameworks as detailed below. We suggest this extension based on our long-term collaboration with Ostrom on developing methods for studying the evolution of action situations over time which she saw as a key future challenge (Ostrom, 2011).

Our point of departure is with the concept of *governance*. Governance is often conceived of as something groups of individuals *do* to solve problems via some mechanism of social choice (e.g. democratically) within a *governance system*. The governance system is composed of a number of elements that structure social interactions whereby social choice occurs. Governance systems can be characterized as action situations or collections of linked action situations. Action situations, in turn, are social spaces where individuals interact, exchange goods and information, dominate one another, engage in conflict, etc. That is, governance is often viewed predominantly from the perspective of *social interaction* and analysis focuses on understanding the likely behavior of individuals in the related action arenas. Ostrom (Ostrom, 2011) suggests that institutional analysis can go further in two directions: 1) better understanding the factors that structure the action situation and 2) understanding how action situations evolve over time through changing perceptions induced by recursive interactions. Our suggested extension of the IAD and SES frameworks is motivated by a third analytical trajectory that combines 1 and 2.

In the IAD framework, the evolution of action arenas has an implicit temporal sequence. First, biophysical conditions, attributes of the community, and rules-in-use combine to form the structure of the action situation. Next, individuals interact within the action situation and produce outcomes. This is followed by an evaluation of the outcomes. Finally, these outcomes may induce actors to change the rules-in-use (at the collective choice level), their perceptions (attributes of the community, or technology (biophysical conditions) through *feedback*. This feedback is explicitly depicted in the IAD framework (Ostrom, 2005) and suggests that the evolutionary dynamics of action situations can be conceptualized as a recursion relation on the system states related to biophysical context (state of the environment, state of technology), attributes of the community (perceptions, knowledge), and institutions (rules of the game) with reasonably identifiable time scales. The notion of governance as the dynamic evolution of action situations is a powerful analytical frame, but the research that underlies the work presented in this special feature suggests we must take care for at least two reasons:

- The notion of governance must more strongly emphasize the importance of features other than social interactions in producing outcomes. The notion of action situations can tend to focus the analysts attention on social interactions. In some cases, outcomes may depend less on social interactions than on other processes and, as a result, the details of social interactions in a particular case may not help us understand "successful governance" in that case. This is especially true for practical aspects of effective monitoring and sanctioning processes that typically receive less attention in the literature than institutional arrangements (understood as rules and norms), trust, and communication.

- It is likely the dynamic evolution of action situations involves interactions at a very large number of time scales that are difficult to identify, giving rise to subtle interactions that are difficult to disentangle. Such a view acknowledges the difficulty, for example, of understanding how formal and informal institutions interact, how institutions interact with perceptions, and how all these interact with technology.

Let us attempt make these abstract statements a little more concrete with examples using Ostrom's notion of the internal structure of an action situation that emphasizes 'institutions as rules' shown in Figure 1 (in black). Here, elements from the seven classes of rules mentioned above determine what positions can be assumed by actors in the action situation such as *chair* or *director* (through **position rules**), which actors may assume those postions, e.g. must be a member of the village, (through **boundary rules**), and what actions actors in positions can take (through **choice rules**). Choices are linked to outcomes via how much information actors have (through **information rules**), and how much control individual actors have (through **aggregation rules**). Potentail outcomes are limited by **scope rules**. Finally, actors make decisions in action situations by assigning costs and benefits to outcomes which are conditioned by **payoff rules**. Thus, by restricting some actions and enabling others, institutions structure the action situation and move the system of recurring action situations toward desirable outcomes. In this view, institutions are protocols that help *animate* social ecological systems given biophysical constraints.

While this view of *institutions as rules* is powerful, the two points above suggests an alternative view that may better characterize some situations. Specifically, the second point suggests that in some situations we may reverse causality and replace "assigned to" with "emerge from" as shown in red. In this case, actors are constantly generating new self images and mental models as they occupy positions in networks of social relations in essence defining new actors and new possible actions. Likewise, the arrows between the action situation and rules regarding information, control, outcomes, and costs and benefits are reversed (again shown in red). In this view, institutions are not rules that guide action and animate social interactions but, rather, are reflections of common knowledge regarding self-sustaining features of social interactions (Aoki, 2007, 2001). Rules are then codified public representations of this common knowledge. Aoki (2007) suggests that we might label the black arrow and text version of Figure 1 as the "exogenous" and the red version the "endogenous" view of institutions. In the endogenous view, institutions are emergent features of the dynamic interaction between the various classes of infrastructure that constitute the action situation generated by a large number of microsituational variables. Lobster fisheries illustrate

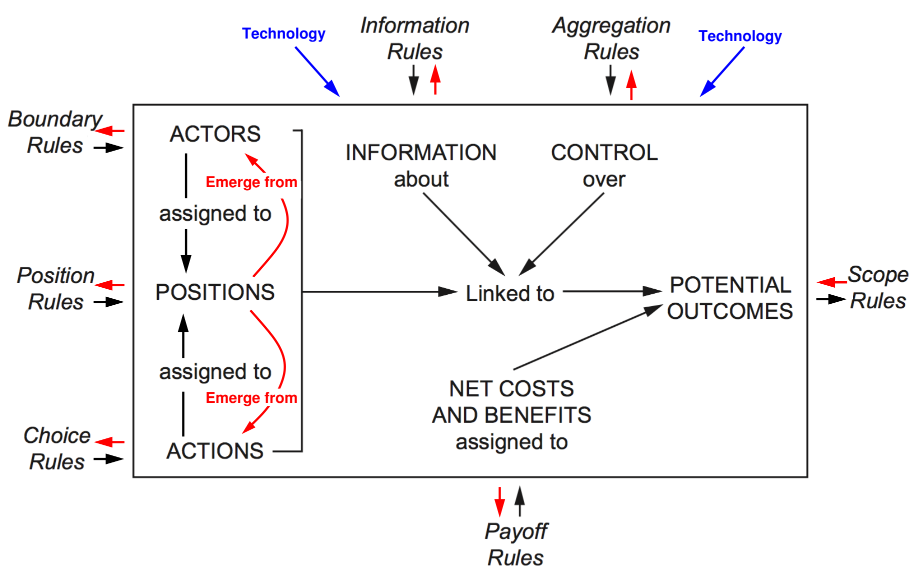

Figure 1: *Ostrom's schematic for the internal structure of the action situation emphasizing the role of rule clusters in structuring action situations. Adapted from Ostrom (2011, Figure 3).*

the importance of the first point. Lobster traps have buoys that convey information about who is fishing where and the way lobster traps are set and recovered strongly conditions catch. Lobstering technology makes the costs of monitoring (buoys are easy to see) and sanctioning (traps are easy to cut/destroy) relatively low. Thus, successful governance of lobster fisheries may have more to do with the specifics of technology than with institutional arrangements. Put simply, a given social ecological system may simply have gotten lucky, by its very constitution, and thus was able to "solve" a perceived (by an outside observer) social dilemma that actually doesn't exist.

This recognition that technology, environment, rules, norms, beliefs, and social bonds are intimately intertwined has motivated us to adopt the term "coupled infrastructure system" rather than "social-ecological systems". This extends our use of public infrastructure and infrastructure providers from the Robustnesss Framework for Social-Ecological Systems (Anderies et al., 2004). The term social-ecological systems implies there are two distinct domains, the social and the ecological that operate by their own logic (although they can intimately interact). The term coupled infrastructure system, on the other hand, suggests that there is only infrastructure, defined as structures of any kind, e.g. genomes, legal systems, roads and bridges, knowledge and value systems, buildings, ecosystems that *provide affordances when combined with other classes of infrastructure* to produce mass and information flows we value. The work in this special issue focuses on how natural (e.g. ecosystems), hard human-made (technology), and soft human-made (institutions) infrastructures interact to produce outcomes in social dilemmas related to public good provision and resource governance.

The work presented in this special feature is organized around Ostrom's Design Principles (DPs). As discussed above, the DPs can be seen as a proxy or metric for soft human-made infrastructure. Based on the case studies, we also have information about characteristics of natural infrastructure up to the sector level (i.e. fisheries, forests, or irrigation systems). With these data, the papers address the following three challenging sets of questions:

1. How do Ostrom's institutional design principles interact with each other. Are there minimal combinations of principles that are necessary for successful CPR governance? Are these minimal combinations also sufficient, or do they require other principles?

2. How does the answer to 1 depend on other types of infrastructure in CISs? Does the set of DPs necessary for success depend on whether the CIS involves forestry, fishing, or irrigation?

3. How do we develop robust empirical methodologies to systematically explore what types of infrastructure characterize "successful" coupled infrastructure systems? What are possible methodological frameworks to accompany the theoretical framework embodied in the IAD?

By attempting to answer these questions, we are searching for patterns of combinations of different classes of infrastructure that may lead to successful CISs. This is an extension of Ostrom's search for patterns in institutional arrangements in successful SESs (a single class of infrastructure).

Searching for organizational patterns in successful CIS

Ostroms DPs were the starting point for the research team reporting their results in this special feature. The basic the approach is straightforward: associate the presence or absence of design principles with "success" or "failure" of examples of CISs. In practice, this turns out to be quite difficult. First there is ambiguity about whether to classify a case as success or failure since both positive and negative outcomes can be observed for different actors in a given system. We therefore measure the success and failure of a number of social and ecological conditions. Second, since the research relies on secondary data, it is not always possible to find sufficient information to determine whether a design principle is present or not. A third challenge relates to the fact that the design principles are not independent - it is likely *configurations of design principles* that affect performance of CISs rather than individual design principles. There are 2,048 possible categories for institutional arrangements that can be constructed from the 11 Design Principles (one in which no DP's are present, 2,047 with at least 1 present). Even though the DP's parse the enormous set of all possible institutional arrangements into a much smaller set of 2,048 elements, exploring this set is still challenging. Further, exploring how DPs interact with the other infrastructure in the CIS expands this set. If we add just the sector information of fisheries, forest, or irrigation systems, the set of categories increases to 6,144 ($3 \times 2,048$).

Baggio et al. (this volume) systematically explore this space of potential interactions between the DP's and other infrastructure using Qualitative Comparative Analysis, a method that enables them to cope with the combinatorial nature of the data. As with all statistical methods, the analysis produces outliers. Barnett et al. (this volume) evaluate these outliers and attempt to explain them using additional contextual data from the case studies. Finally, and perhaps the biggest challenge, is the replicability of the coding process . Earlier coding exercises found in the literature are not precise about their coding protocol. Ratajczyk et al. (this volume) document in more detail the coding protocol that was used, what challenges were experienced, and how they were addressed.

Baggio et al.'s (this volume) suggest that, in fact, DPs occur in clusters and success depends on having "enough" DPs. Cases with fewer than 4 DPs will likely fail. Cases with more than 9 will likely be successful (all cases with more than 9 DPs in the data set were successful). The analysis also strongly suggests that DPs in isolation do not contribute to success. Only when clusters of DPs are present is there success. The analysis further suggests that interactions with other infrastructure is an important determinant of success. Namely, fishery and forestry cases have a higher likelihood to be successful at lower numbers of DPs and the co-occurence of DPs exhibit different patterns depending on resource type (i.e. nature of the natural infrastructure) across fishery, forestry, irrigation systems. Considering cases with no missing data, Baggio et al. go further to suggest that a necessary condition for success was that 4 specific DPs were present. The presence of these DPs, although necessary, was not sufficient for success. They had to be combined with other DPs, depending on the specific case, to insure success.

These results are interesting, but no conclusion on causal relationships can be drawn. Moreover, there are remarkable outliers Put simply, there are examples of cases where all or nearly all of the DPs were present and yet they were deemed failures. On the other hand, there were examples in the data set that were successful despite the fact that there were *no design principles* in the case. Barnett et al. label these two types of inconsistencies as "Type I" and "Type II", respectively. Inconsistent cases can arise from several causes: 1) investigator bias in primary data analysis, 2) procedural bias in secondary data analysis, and/or 3) substantive error in which there are alternative contextual factors or multiple pathways that may account for an outcome. In the first case, for example, the original case author simply did not detect or report on a DP even though it may have been present. In the second case, error can be introduce by the coders reading the primary case authors documents. Ratajczyk et al., this volume, discuss these issues in detail.

Barnett et al. identify key patterns that may underlie the inconsistent outcomes that may have resulted from alternative contextual factors. Consistent with the CIS perspective, they find that these inconsistencies have to do with interactons between the DPs (which relate to institutional infrastructure) and other types of infrastructure. A careful analysis of 5 Type I cases and 4 Type II cases reveals the following patterns. For Type I inconsistencies, the main reasons why DPs may not be sufficient are 1) essential principles absent, 2) strong influence of external actors (non-state in the specific case examined), and 3) market integration and values. For Type II inconsistencies, the main reasons for success in the absence of DPs are 1) lack of market integration, resource abundance in relation to population size, 2) internal cohesion of communities due to kinship ties, 3) technology, and time-lags and 4) political economy shifts.

Taken together, the results of Baggio et al. and Barnett et al. point to a general principle core to the CIS perspective: there is likely no robust way to sufficiently isolate different infrastructure types for analytical purposes. That is, in the language of Ostrom's IAD framework we can never isolate the action situation from the "external variables" when we are considering the institutional design for the "success" of CISs over time. If we are interested in *understanding* social interactions and outcomes of groups engaged with shared resource governance on daily or weekly timescales, such isolation may be possible. But for *design*, all infrastructure must be treated as endogenous to the CIS.

The special feature concludes with a reflection on research methods in the area of CIS by Ratajczyk et al. The challenge is that the data associated with each CIS is very complex. This fact often presents researchers with a stark choice: study one or a small number of cases in great detail or study a large number of cases using very course-level indicators. Working in between these extremes is a huge effort, but is clearly one direction that future research must go if we are to sharpen our understanding of how institutions function in the context of CISs of which they are constituent parts. Ratajczyk et al. highlight the need for all researchers, but especially those using and creating secondary data, to document their assumptions and interpretations. Further, they argue that full disclosure of supplementary coding information and intercoder reliability ratings are essential practices if we are to move the difficult science of governance of CIS forward.

The three papers presented as part of this special represent a small step forward. The remaining work is daunting and will require a concerted effort by all scholars of environmental governance and the commons to establish shared protocols for data structures, data generation, and analysis at the international level.

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