Heterogeneity in the Commons: Hard Infrastructure and its Effects on Collective Action and Public Goods Provisioning

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I. Introduction

Contemporary irrigation management practice, while inheriting many notions of community tradition, employs its own generalizing models, which (often drawing on institutional theory) emphasize local irrigation institutions as self-managed organizational solutions to problems of task fulfillment and the distribution of material benefits [35]. Much of the literature cites cooperation as the reason for efficient management of common-pool resources (CPRs) by communities [11, 12, 35]. However, cooperation necessitates collective action by the community to form rules regarding resource use, as well as monitoring and enforcement mechanisms. Since these actions involve costs, cooperation will prevail only if the benefits of cooperation outweigh the costs [30]. Therefore, the likelihood of cooperation is highly dependent on the characteristics of the system that influence the gains from working together[8, 35, 43]. There is substantial literature that focuses on either lowering monitoring costs [24, 43] or strengthening rule enforcement mechanisms [24, 25]. However, hard human-made infrastructure also plays an important role in mediating social- and human-environment interactions and fundamentally shaping the dynamics of coupled social and natural processes [2, 3, 16] which remains largely unexamined in the literature. We hope to contribute to this discussion by examining how the design of hard human-made infrastructure can affect the capacity of people to solve social dilemmas and maintain vital functionality of the system in the face of shocks and exogenous

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drivers.

The purpose of this paper is to begin establishing a typology for understanding the impact of hard infrastructure on the prospects of collective action with specific reference to the rules-in-use related to common pool resources (CPRs). More precisely, we will argue that as the heterogeneity of the hard infrastructure increases, the efficiency achieved by regulation decreases due to increasing incongruence between the rules-in-use, the appropriation and provisioning behavior, and the local conditions. In order to make the presentation more vivid, whenever possible, the various points we make will be illustrated by referring to five cases (three artisanal fisheries and two small-scale irrigation systems [1]) in Arizona State University's Social-Ecological Systems (SES) Library [2] and findings from other in-depth case studies conducted by social scientists.

II. Heterogeneity, Congruence, and Fit

This paper utilizes the concept of congruence as outlined in Elinor Ostrom's design principle 2 (DP2) (congruence between appropriation and provision rules and local conditions) [35]. Here, we are assessing whether "the prevalent appropriation rules restricting time, place, technology, and/or quantity of resource units are related to local conditions and to provision rules requiring labor, material, and/or money" [10]. It has been asserted that DP2 is the only design principle that tests whether resources are being utilized sustainably [38]. However, it is currently unclear whether both of the subparts that combine together to create DP2: (1) congruence between appropriation and provision rules; and (2) congruence between appropriation rules and local conditions [10] are always present in coupled infrastructure systems (CISs)s that are managed sustainably, or if the presence of only one of the two is sufficient. In the three fisheries cases we analyzed, we found evidence that both elements of DP2 are either absent or significantly impaired and the target species in the fisheries reflect evidence of significant over-appropriation.

Fit is defined as the effectiveness of institutional arrangements to "prevent undesirable

[1] Fisheries Cases: 9,10, and 15; Irrigation Cases: 53,60, and 73

[2] `https://seslibrary.asu.edu/seslibrary/welcome`

environmental changes and to solve environmental problems once they arise?" [44]. The "problem of fit" hinges on the compatibility or congruence between resource systems and the institutions that are created to manage the human activities impacting those resource systems [11, 13]. Heterogeneity in CISs increases the complexity of fit, as does the horizontal (same level of social organization) and vertical (cross-scale interactions or links involving institutions at different levels of social organization) interplay of institutions [44]. In this paper, we draw on the concepts of congruence and fit to evaluate how well institutions provide a framework within which resource extraction is balanced by the provisioning - development, maintenance, and protection - of the resource [39].

In recent years, a number of theoretical papers and literature reviews have been published which reevaluate the established view that heterogeneity has a negative impact on community resource management, or management of common-pool resources more generally [5, 7, 9, 17, 37]. The development literature has emphasized the importance of cooperation within social groups and communities to solve a wide range of economic problems that neither the market nor the state can effectively tackle alone [14, 18, 23, 27, 35, 36, 42]. The question as to which factors are more conducive to successful collective action has therefore recently received a lot of attention from a large number of scholars in different social sciences. Probably the most salient conclusion which emerges from this literature, including the research of economic theorists, concerns the crucial role of group size: the smaller the group the stronger its ability to perform collectively. A more debatable issue concerns the role of inequality. Olson [34] contended that more heterogeneity may favor the creation of public goods. In this study, by heterogeneity, we refer to the inequalities in ownership of hard infrastructure that may arise due to or as a result of inequalities in wealth, income, access to credit, etc. as well as socio-cultural differences; that is differences in ethnicity, caste, class, religion, etc. and/or in cultural view of the resource [4, 17]. Our current analysis is mainly focusing on how heterogeneity in hard infrastructure is influencing appropriation and provisioning patterns. In the future, we intend to broaden our examination to account for other infrastructures within CISs that are affected by and/or

affecting heterogeneity in hard infrastructure.

The dominant economic approach to collective action in a CPR consists of analyzing the individual incentives to cooperate [30, 35]. Such incentives are determined by the private benefits and costs resulting from participation in collective action. From a static perspective, the distribution of benefits reflects the distribution of rights of access to the CPR which is itself influenced by the distribution of wealth endowments. Thus, some users enjoy better access to the CPR because they possess a relatively better bundle of infrastructures required to exploit it (capital equipment, control over labor power, better skills and knowledge, etc.). This advantage may originate in past accumulation of wealth, greater network of social relations, better education, or in privileged access to markets where critical inputs such as credit and manpower can be obtained. In reality, many of these infrastructures are closely interlinked. Furthermore, when collective action involves active steps to conserve the resource, costs are usually incurred in the current period while benefits accrue at a later time. The present value of the net expected benefits depends on the structure of the users' time preferences. Thus, users those with a shorter time horizon typically adopt strategies which yield more immediate results, and disregard longer-term considerations in resource conservation. Variations in time horizons are actually related to the initial distribution of wealth either through the intervention of hard infrastructure or through the availability of outside economic opportunities [5]. The choice of hard infrastructure affects the future state of the resource and hence, users' payoffs correspond to the present values of all (discounted) future incomes.

Due to their varying wealth endowments, it can be argued that wealthier users are more patient, i.e., the discounted value of their future benefits tends to be higher than that of poorer users. The payoffs they obtain from adopting a resource conserving strategy are therefore higher. The key point of our argument is that the nature of the resource (public good vs. open-access) and appropriation infrastructure mediate the relationship between appropriation and provisioning by affecting the size of payoffs (incentives to cheat vs. sanctioning costs). The resulting appropriation and provisioning patterns ultimately have a feedback effect on

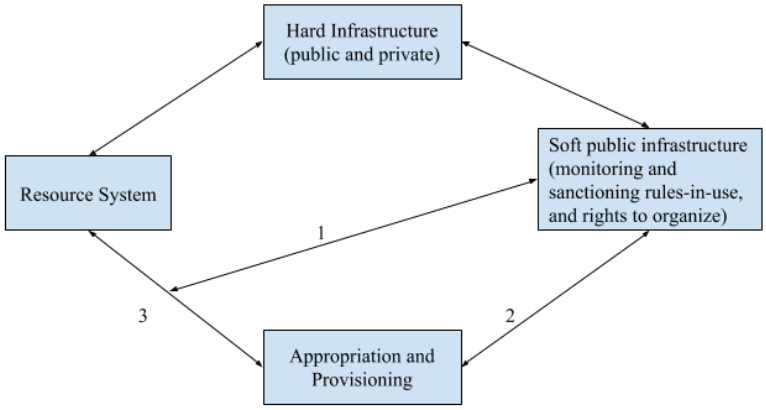

Figure 1: *Infrastructure feedback loop reflecting interaction between natural (resource system) and hard and soft human-made infrastructures and the feedbacks that affect congruence with common pool resource arrangements and the overall fit of human-made infrastructure with the biophysical context within which they are embedded. This is a detailed parsing of the public infrastructure section of the robustness framework [3]. We argue that the resource system dictates the type and heterogeneity in hard infrastructure. The heterogeneity in the hard infrastructure, in turn, influences the enforcement mechanisms, which affect the incentives of resource users to over-appropriate or under-provide. The appropriation and provisioning patterns then ultimately affect the condition of the resource. We also argue that the heterogeneity in hard infrastructure may arise from or result in other types of infrastructures (soft, social, and human) that are embedded in this coupled infrastructure system. Links 2 and 3 represent the congruence between appropriation and provisioning rules and local conditions respectively. Link 1 reflects the fit of the institutions to the local condition of the resource, which is mediated through the appropriation and provisioning patterns.*

the condition of the resource. In summary, our hypothesis is that the optimal rate of resource extraction is linked to enforcement expenditures that increase with the incentives of individual members to cheat with the enforcement expenditures themselves being an increasing function of the heterogeneity in hard infrastructure (Figure 1).

III. Inferences from Case Studies

Gaspart et al. [22] show through their analysis of the watershed management program in the Ethiopian Highlands that the provisioning of public hard infrastructure depends on the potential benefits that individuals derive from or the investment they make into their hard

infrastructure. In his in-depth study of irrigation systems in South Indian villages, Wade cogently argues that the effectiveness of a local irrigation council "depends on its councillors all having a substantial private interest in seeing that it works, and that interest is greater a larger a person's landholding.... The claims that big landowners can make "are sufficiently large for some of them to be motivated to pay a major share of the organizational costs" [43]. Similarly, in Ha Nchele, a lowland village in Lesotho, rotational grazing has been successfully introduced on village grazing lands as an alternative to taking animals to a cattle post in the mountains, mainly because the village chief held the greatest number of livestock, and thereby took a predominant part in the development of the project [40].

In the Nabagram canal irrigation system in Bangladesh [15], all farmers rely on the water being distributed successively from one block to another during the post-planting period. A water distributor is employed to determine when an individual plot has received an adequate supply of water and to divert the water flow from one plot to another. By taking the water allocation process out of the hands of individual irrigators and harmonizing the appropriation infrastructure, the costs of monitoring and sanctioning were reduced, thereby decreasing the chance of rule violations. The accountability of the water distributor to irrigators reduced the chance of infractions. In contrast, in the Sananeri tank irrigation system in South India [31], a few farmers owned private pump-sets/wells, which gave them an advantage over other irrigators during times of water scarcity. In this system, although rules prevent the use of groundwater irrigation simultaneously with tank water, enforcement of this regulation is difficult due to (1) dominance of the well-owners who generally are wealthier individuals, and (2) the open-access nature of groundwater that enables farmers to claim private property rights over the water beneath their farming land. Based on the assertion by Baland and Platteau [6], an argument can be made that a higher degree of heterogeneity in hard infrastructure results in greater inefficiency in the use of the CPR due to higher monitoring and sanctioning costs. This argument is also supported in Johnson and Libecap's analysis of the failure of cooperative mechanisms for catch restriction in the over-capitalized shrimp fishery of Texas [25]. In their

own words:

> *"Contracting costs are high among heterogenous fishermen, who principally vary with regard to fishing skill. The differential yields that result from heterogeneity affect the willingness to organize with others for specific regulations....regulations that pose disproportionate constraints on certain classes of fishermen will be opposed by those adversely affected. (...) For example, total effort could be restricted through uniform quotas for eligible fishermen. But if fishermen are heterogenous, uniform quotas will be costly to assign and enforce because of opposition from more productive fishermen. Without side payments (which are difficult to administer), uniform quotas leave more productive fishermen worse off."* ([25]: 1006,1010)

In the Nicaraguan turtle fishery[3], the introduction of private hard infrastructure, such as turtle fishing nets and motorized boats, has in the past facilitated and continues to promote the over-appropriation of endangered green turtles both by fishing effort and via entry to the fishery by less experienced fishermen. Access to outside markets has incentivized the increased use of these new hard infrastructures leading to the abandonment of traditional fishing norms and reciprocal food exchanges in favor of year-round commercial exploitation of for more individualistic cash profit considerations. The absence of monitoring and sanctioning mechanisms has enhanced these incentives [21, 29, 32, 33].

In the Greek lagoon fishery[4], the *dejure* laws stipulate access rights and types of fishing gear for cooperatives and independent fishermen. Cooperative fishermen can utilize motorized boats, fences, and fish traps to harvest fish as they migrate in and out of the lagoon. However, in exchange for their access rights, they have to compensate the government in the form of a tax rate on the gross value of their catch. Furthermore, cooperative fishermen incur large up front capital investment costs to purchase fences, traps and nets, as well as ongoing maintenance expenses to keep everything in working order, leading to incongruent CPR management decisions that favor over-appropriation, undercutting of appropriation rules, and underreporting of catch sizes [28].

[3] `https://seslibrary.asu.edu/seslibrary/case/15/view`

[4] `https://seslibrary.asu.edu/seslibrary/case/9/view`

Independent fishermen have legal access rights to an unleased portion of the lagoon and are not required to compensate the government for the amount of fish they harvest. However, their harvesting ability is restricted by regulations limiting hard infrastructure to non-motorized boats, long-lines and spears. Poverty and to some degree the inability to join a cooperative due to willful exclusion by cooperative members facilitates rule violations and over-appropriation similar to that of cooperative fishermen [28].

In the traditional Thai kembong fishery (1956-1964)[5], new technologies and better access to local markets combined with the accepted norm that the ocean should be open to everyone inhibited the creation of harvesting rules and gear restrictions that would have limited kembong exploitation. The incongruence between *defacto* rules and CPR management arrangements led to the over-appropriation of kembong [19, 20]. In the contemporary fishery, poorly coordinated top-down rules and bottom-up decentralization efforts, along with improper funding of the agency responsible for implementation, monitoring and sanctioning of the fishery enables excessive commercial exploitation of kembong and other fish stocks with damaging gear. Additionally, the national government's focus on meeting international fish demand is inhibiting rule creation and implementation that would curtail commercial fleets from encroaching on the inshore coastal areas of small-scale fishermen [1, 26, 41].

IV. Conclusion

First, it must be emphasized that the conclusions reached in this paper are based on a very small sample set of secondary case studies. Furthermore, the research that we are drawing on was not necessarily written with a CIS perspective in mind meaning that some elements important to a detailed CIS analysis may be unaddressed in the texts. However, even though our findings are preliminary and necessarily incomplete, we believe important tendencies have been revealed which will benefit from a more rigorous follow up examination drawing on a greater number of case studies. An important general implication of the above discussion is the following:

[5] `https://seslibrary.asu.edu/seslibrary/case/10/view`

until the rules-in-use take into consideration the varying costs and benefits to actors due to heterogeneity in hard infrastructure and mete out equal treatment to all actors regarding use of local CPRs, the regulated outcome may be expected to be socially and ecologically inefficient, as our brief review of select case studies has revealed.

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