

International Journal of the Commons

Vol. 12, no 2 2018, pp. 191–216

Publisher: Uopen Journals

URL:<http://www.thecommonsjournal.org>

DOI: 10.18352/ijc.851

Copyright: content is licensed under a Creative Commons Attribution 3.0 License

ISSN: 1875-0281

Social capital, institutional change, and adaptive governance of the 50-year-old Wang hilltop pond irrigation system in Guangdong, China

Ying Chai

National Economics Research Center, Guangdong University of Finance and Economics, China
chaiying19@163.com

Yunmin Zeng

Center for Environmental Economics and Policy Research, Guangdong Academy of Social Sciences, China
amao1604@163.com

Abstract: This study investigated a community-managed irrigation system, the Wang hilltop pond irrigation system (WHPIS) in Guangdong, China. Via a field survey and case study, this paper describes the WHPIS's two-stage process of evolutionary governance since the 1960s. First, it explains how the WHPIS achieved 50 years of successful self-governance and robust operation. Then, based on the requirements for adaptive governance outlined by Dietz et al. (2003), it addresses how the WHPIS, when faced with a climate-anomaly, has achieved robustness through institutional change. It finds that with strong social capital based on lineage events, the community, working in partnership with the local government, collectively revised investment, maintenance, and water distribution rules, and developed a new patroller rule. These new rules were effectively enforced by the community through social capital, which enabled the WHPIS to adapt to the climate anomaly. Last, this study concludes that a long-term self-governing irrigation system disturbed by abrupt change can be restored to a robust state via institutional measures enabling adaptive governance. Strong social capital enables a community to absorb the external power from the local government and internalize it, enforce incremental rule changes, and efficiently achieve a robust irrigation system subject to adaptive governance.

Keywords: Adaptive governance, climate anomaly, incremental institution change, irrigation system, lineage, social capital

Acknowledgements: This research was financially supported by the National Natural Science Foundation of China (Grant No. 71303062), the National Social Science Foundation of China (Grant No. 15BGL146 and 17BJY066), Humanity and Social Science Foundation of Ministry of Education (Grant No. 18YJA790009), Natural Science Foundation of Guangdong (Grant No. 2018A030313451), and the Major Applied Project for Universities of Guangdong (Grant No. 2017WZDXM011). We are grateful to the anonymous reviewers for their helpful comments and suggestions. We acknowledge the interviewees in relation to the WHPIS for their support during our field survey. Many thanks go to Geoff Whyte for English language editing.

1. Introduction

The problem of governing irrigation systems challenged by external disturbances has gained increasing attention in recent years (Dietz et al. 2003; Araral 2013a; Yu et al. 2015; Lam and Chiu 2016; Wang et al. 2016; Villamayor-Tomas 2017). Even well-performing and long-lasting irrigation systems run the risk of frangibility and might break down when exposed to an external disturbance (Janssen et al. 2007; Cárdenas et al. 2017). External disturbances indicate unexpected changes in the environment, typically climate change, which breaks the normal service flow of the irrigation systems (Villamayor-Tomas 2017). Although some systems are generally robust, they are also characterized as having trade-offs (Anderies et al. 2004) and can easily lose essential functions with changes in the ecological, sociological, and economic environments. This has been seen in the Indonesian subak system (Lansing 1991), the Spanish irrigation community in Murcia (Pérez et al. 2011), the Nepalese irrigation systems (Bastakoti and Shivakoti 2012), and the American Taos Valley (Schoon and Cox 2012). Therefore, scholars and policy-makers are currently facing the challenge of how to maintain a robust irrigation system while also minimizing its frangibility in the face of external disturbances.

Adaptive governance is highly endorsed as an effective way to maintain robust social-ecological systems (Dietz et al. 2003; Schultz et al. 2015; Lam and Chiu 2016; Roggero et al. 2018). Various scholars also justify the importance of social capital in enabling the community to implement adaptive governance. Based on the rationale of adaptive governance, frangibility occurs if institutions are unable to adapt to the changed irrigation system. Therefore, to minimize potential frangibility these institutions must evolve (Nelson et al. 2007). Theoretically, adaptive governance involves four important aspects. First, adaptive governance indicates that institutions require change consistent with the external disturbance. Effective institutions are temporary (Agrawal 2008). Second, the prerequisites for adaptive governance include providing necessary information, dealing with conflicts, complying with rules, supplying infrastructure, and encouraging adaption and change (Dietz et al. 2003). Third, the enforcement of low-cost adaptive governance requires various forms of social capital, including trust and cooperation, within the irrigation community. As demonstrated by the farmer-managed irrigation sys-

tems in Nepal, strong social capital contributes to institutional transformation and an adaptive capacity in response to environmental changes (Thapa et al. 2016). Last, regarding the pathway to adaptive governance, irrigation institutions should be adjusted incrementally, while social capital with the community should remain unchanged (Aligica and Tarko 2014). Institutional change should be bottom up from the community, and attempts to seek external assistance should start within the community (Murtinho et al. 2013). In general, an irrigation system can achieve synergetic robustness instead of trade-offs in the advent of a disturbance if the community transforming institutions has strong social capital.

Theoretical work on commons governance has stated that social capital is crucial if a community is to achieve sustainable robustness (Meinzen-Dick 2007). Social capital is shared knowledge, understandings, norms, rules, and expectations about patterns of interactions that groups of individuals bring to a recurrent activity (Ostrom 2000). Field research suggests that an irrigation community should maintain social capital, which is strongly positively associated with successful responses to external interventions (Lam and Chiu 2016). Otherwise, as field experiments have shown that external regulation results in a crowding out effect by controlling community activity because of a lack of social capital (Cárdenas et al. 2000). The greater the loss of social capital suffered by a community, the less robust its irrigation system (Vollan 2008). Meanwhile, a community should maintain strong social capital with outside bodies such as local government to better understand region-level policy and objectives (Meinzen-Dick 2007). To strengthen social capital, a community requires good communication, capacity building, autonomy reinforcement, and institution completion (Fabricius and Collins 2007; Cifdaloz et al. 2010; De Fraiture et al. 2014).

The aforementioned studies provide insights into the relationship among social capital, adaptive governance, and sustaining irrigation systems. However, three important problems remain under-studied. (1) What are the institutional structure of a long-lasting irrigation system and the evolutionary process of institutional change in adaptive governance? (2) How does social capital contribute to effective institutions enabling a community to maintain system robustness in climate disturbance? (3) Which institutions should be transformed and how, and what conditions should remain unchanged? The main objective of this study is to fill this gap in the literature through systematically clarifying these issues.

This paper uses the Wang hilltop pond irrigation system (WHPIS) as a case study to examine these issues. Built on a hill, a hilltop pond is a small reservoir with a water storage function. Water is collected via rainfall and springs. Like other HPISs,¹ the WHPIS is a typical community-managed commons in China's Guangdong province that has been performing well and sustainably for 50 years.

However, there have been few studies examining the successful operation of self-governing HPISs. Following Ostrom's (1990) overarching study of governing

¹ In the 1960s, Guangdong launched a campaign to construct HPISs, with approximately 50,000 HPISs built throughout the highlands. Almost every village has an HPIS.

the commons, various community-managed irrigation systems are well known, including the Spanish huerta, Philippine zanjera, Swiss felderin, and farmer-managed systems in Nepal, Tanzania, Indonesia, Iran, Thailand, and Bangladesh (Tang 1992; Araral 2013a). However, successful cases from China have not been studied. International literature on irrigation governance in China has focused on centralized management by the state (Wittfogel 1957; Yu et al. 2005) and decentralized management by a range of participants including farmers (Wang 2006; World Bank 2007), farmer water users' associations (Zhang et al. 2013; Wang et al. 2016), and contractors (Huang 2014). These studies generated the illusion that there are no local institutions crafted from the bottom-up by the irrigation community in China. In fact, Guangdong, a province in southern China, has many HPISs successfully governed by local community. Therefore, another goal of this study is to highlight these community-managed irrigation systems and to reveal the diverse practices in governing the commons in China.

The rest of this paper is organized as follows. Section 2 presents the analytical framework and methodology, illustrates the relationships among social capital, institutional change, and adaptive governance, and elaborates on the case selection and field survey process. Section 3 introduces the WHPIS, its governance structure, and sustainable self-governance in the early years. Section 4 uses the adaptive governance framework to analyze the WHPIS's successful adaptation in response to climate anomalies. Section 5 discusses the reasons for the sustainability and robustness of the WHPIS and Section 6 concludes by providing a summary of insights into adaptive governance for theory extension and policy-making.

2. Analytical framework and methodology

2.1. Analytical framework

This study explores the mechanism by which institutional change through social capital meets the needs of adaptive governance in response to disturbances caused by climate anomalies. The intuition is that adaptive governance is an effective approach through which institutions change in response to climate-related disturbances, as shown in the analytical framework on which this study is based (see Figure 1).

This analytical framework builds on the work of Dietz et al. (2003), who claim that adaptive governance is an important means of solving critical problems related to commons and summarize five conditions necessary to achieve success. Condition 1: the state of resources and the process of using resources can be monitored, verified, and understood at a low cost. Condition 2: moderate change in the rate of use of resources, users' size, and technology, the economy, and social conditions. Condition 3: the community can communicate frequently and has a strong social network-also called social capital-that can improve trust, enable people to express and observe emotional reactions to defections, and reduce the cost of monitoring and rule compliance. Condition 4: excluding outsiders from using the resources costs little. Condition 5: resource users support effective monitoring and enforcement of the rules.

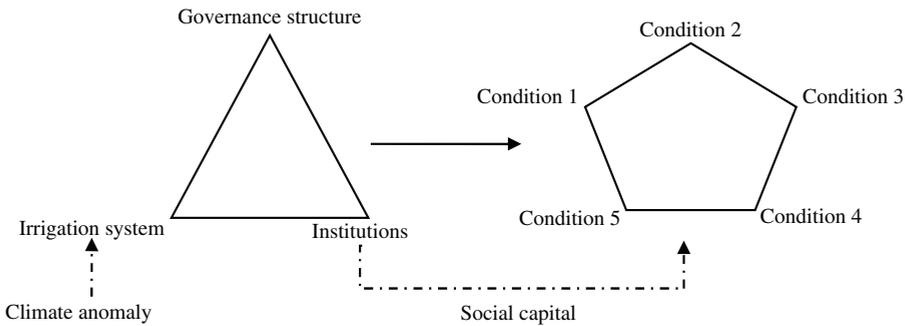


Figure 1: Analytical framework incorporating social capital, institutional change, and adaptive governance.

These five conditions set the criteria by which effective institutions should be judged. They also provide guidance in terms of the ways in which institutions should adjust when any of the conditions change. This study discusses institutions at the operational level in terms of the rules that shape participants' behaviors. As stated by Roggero et al. (2018), institutions can provide coordination and cooperation to help resolve the dilemmas of infrastructure maintenance and water distribution that are inbuilt in an irrigation system. The rules in use will be highlighted to resolve the conflicts caused by collective actions in response to these dilemmas. Effective institutions regarding community-managed irrigation systems take on various forms, and no single blueprint fits them all (Ostrom 1990). Following the logic presented by Araral (2013b), whereby the appropriate institutional choice is determined by the physical geography in which the irrigation system is embedded, it is reasonable to assume that the governance regime, namely, communal management, will remain consistent and incremental institutional changes will appear in institutions when external disturbances such as climate anomalies occur.

Similar to traditional governance, adaptive governance has an in-built second-order dilemma regarding institution provision. To keep the commons robust, the implementation of and change in institutions should occur at a low cost, which can be achieved by the existence of social capital. Following Ostrom (2000), this study explores social capital at the community level. In the WHPIS, social capital is accumulated both inside the community and outside the community with the local government. Regarding the former, social capital takes three forms, namely, reciprocity, reputation, and priority. Reciprocity suggests that because everyone requests help from others, people should respond favorably to each other when dealing with joint benefits. Reputation means that if violators' behavior becomes public, they could be isolated and excluded by others. Priority refers to consensus in relation to water appropriation, in particular that upstream farmlands are able to take water first and downstream farms are prepared to accept this fact. Regarding the latter, social capital is developed through informal interactions between the community and the government.

In summary, in our analytical framework, adaptive governance is a means by which institutions adjust to cope with external disturbances. This process involves two types of challenges. One involves addressing the essence of effective institutions: what rules in use are, which of those rules should change, and how they should change. The other challenge involves overcoming the cost barrier to institutional design, change, implementation, and compliance all of which can be minimized through social capital.

2.2. Methodology

We chose the WHPIS as a representative case study to investigate the role of social capital in institutions throughout its two-stage process of evolutionary governance. The selection of this case study is based on theoretical considerations and practical observations.

In theory, the research subject should be a type of self-governed commons, thus HPISs, as commons that feature communal governance, are appropriate. As Araral (2013b) notes, the institutional choice of an irrigation system is determined by physical geography. In this sense, HPISs were originally constructed as communal irrigation systems to mitigate the risk of unpredictable water supply. From meetings with officials responsible for irrigation management at the city and town levels across Guangdong, we confirmed that the climate, biophysical conditions, and community attributes related to HPISs are similar in mountainous areas. We also learned that HPISs share a similar governance structure, with the community taking on management through social cooperation.

Then, we found that among the mountainous areas, Genghe, which is located in Foshan, is one of the largest agricultural regions, and is highly dependent on HPISs for paddy rice production. Through discussion with key informants in Genghe and investigation of detailed documents, we identified the WHPIS as the study area. The WHPIS is an important and representative case for three reasons. First, the WHPIS possesses many of the comprehensive features of HPISs, presents great diversity in institutional arrangements for infrastructure provision and water use, and exhibits a clear relationship between climatic disturbance and institutional change.

Second, with successful experience in responding to external disturbances, the WHPIS is suitable for an exploration of adaptive governance. There is a rich body of historical information about the WHPIS, its governance structure, and the rules in the various stages of sustainable governance. The changes in terms of climate anomalies, institutional evolution, and people's behaviors that occurred in the WHPIS during the process of adaptive governance have been identified. The entire process that the WHPIS experienced, from suffering a shock to achieving robustness, provides sufficient evidence to enable us to explore the mechanism of adaptive governance.

Third, the WHPIS community has a well-developed lineage and strong social capital which is useful for tracing the background of institutional formation and

subsequent change. In contrast to the studies by Janssen et al. (2007) and Anderies et al. (2004), the WHPIS provides a good case study to address the mechanism of how social capital can incentivize a community to achieve robustness without a fragility trade-off. Hence, the conditions that exist in the WHPIS fit the analytical framework of this study.

The survey for this study was conducted between September–November in 2016. The data were collected from written documents (including statistical and meteorological yearbooks, and government regulations) and interviews with farmers and managers in the irrigation community (including public servants, the village cadre, lineage leaders, and farmer group leaders). Interviews were conducted using structured checklists that comprise six parts: general information, biophysical conditions, community attributes, rules in use, climate disturbance, rule changes, and performance evaluation.

We conducted in-depth interviews with 17 managers and nine households. The managers were purposely selected from different entities (six from local government irrigation and agriculture departments, four from the village committee, three from lineage, three from farmer groups, and one patroller). We contacted each person individually and scheduled an appointment. We also undertook a day of fieldwork with the WHPIS patroller. During the course of fieldwork spent visiting the WHPIS, we obtained broader information about the study area in terms of watershed context, hydraulic conditions, irrigation practices, and topography.

The interviewed farmers were from different households. To ensure maximum coverage for system-level information, we used a random selection process in choosing the subjects. We obtained a list of all the households along each of the three canal branches of the WHPIS, and three households were chosen from each of the upstream, midstream, and downstream areas. All of the farmers engaged in rice farming are over 40 years old. However, there are subtle differences in age and gender along the three branch canals. Most of the farmers in branch 1 are women. Most farmers in the downstream region of branch 2 are males who are older than the farmers in the upstream and middle stream regions. The farmers in branch 3 are of similar gender and age. On average, each interview lasted for 90 minutes. A few interviews took longer because the respondents spoke Cantonese and needed translation from Mandarin.

3. The WHPIS

3.1. Background of the WHPIS

The WHPIS is located in Zehe village in the southern part of Genghe town of Foshan, Guangdong. The WHPIS provides water to a traditional farming community of 51 households. Farmers grow two crops of paddy rice each year. The early crop is for market and is normally sold at a local price of 2.6 Chinese yuan/kg (1 Chinese yuan = 0.16 US dollars). The later crop is kept for food. The WHPIS irrigates an area of about 250 mu (1 mu = 0.067 hectare). Farmlands are very small, just 1 mu per capita on average (see Table 1).

Table 1: Information relating to the study area.

| | WHPIS | | WHPIS |
|--------------------------|---|--|---|
| Location | Zehe village, Genghe town, Foshan, Guangdong (longitude 112.89, latitude 22.89) | Population | 51 households |
| Construction year | 1960s | Family name | Zeng |
| Production system | Irrigated rice farming | Traditional festivals | Spring festival, Tomb Sweeping day, Dragon Boat day, Mid-autumn day |
| Farmland area per capita | 1 mu ^a | Characteristic of households/farmers | High homogeneity |
| Cropping intensity | Two crops | Average age of farmers engaged in rice farming | Over 40 |
| Market integrity | Early crop for sell, later crop for self-consumption | Situation of young members of households | Outside employment |
| Topography | Mountainous | Water fees | Free |
| Water source | Most from rainfall and the rest from spring | Water amount for irrigation | 10 cm height, or 333.5 m ³ /mu |
| Storage capacity | 60,000 m ³ | Paddy rice yield | 500 kg/mu |
| Branch canals | 3 | Price of paddy rice | 2.6 yuan ^b /kg |
| Rainfall | Unbalanced | Institutions | Informal rules |

^a1 mu = 0.067 hectare, ^b1 Chinese yuan = 0.16 US dollars.

The WHPIS has a simple but well-functioning structure. According to the system types classified by Tang (1992), the WHPIS is a simple system concerned with the production and distribution of water to one area of use. It entails a production source (hilltop pond), distribution source (main canal), use source (three branch canals), resource users (farms), and a spillway (see Figure 2). Farmers can take water directly from the branch canals to irrigate their farmland.

The Wang hilltop pond is an independent water source; ringed by hills on three sides, and collects rainfall and spring water via a man-made dam that has a storage capacity of 60,000 m³ and is seven meters deep. The dam acts to keep the water inside the pond, but the water level must be lower than the top of the dam for safety reasons. The spillway is located on the other side of the pond and drains the water naturally to avoid water going over the top of the dam if a flood occurs. These two structures were constructed with basic crafts and are easy for the community to maintain.

The stepped sluice gate is a critical component of the Wang hilltop pond. It is made of concrete, and was designed by hydraulic engineers in the 1960s. The stepped sluice gate characterizes a complex structure. It has seven steps, each of which is one meter high with a round hole at the top enabling water to enter. Water proceeds through each step, from highest to lowest, via the holes. The stepped sluice gate is also used as a tool to measure the water level. When the water level

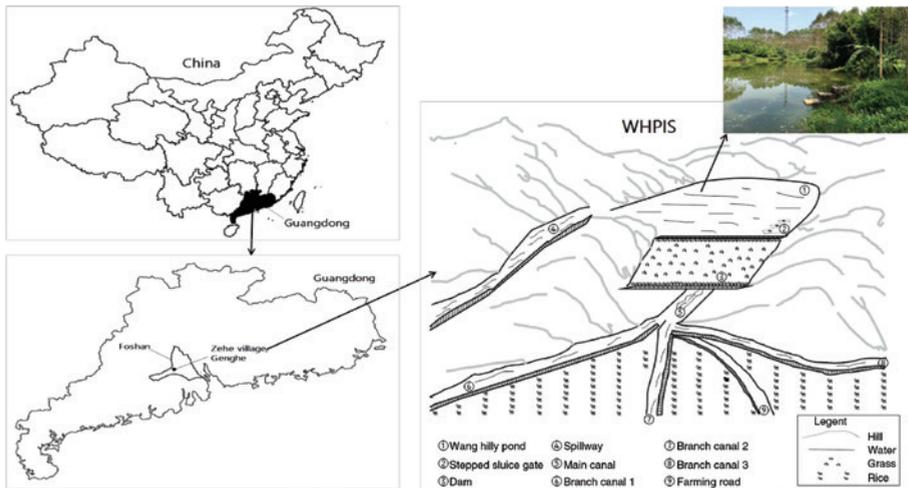


Figure 2: Map of the WHPIS.

is at step VII (the highest step), the pond is full; when it is between steps III and IV, the pond is half full. In Figure 1, two and a half steps can be seen above the water level, which indicates that the water is 4.5 m deep.

The WHPIS has three branch canals, each of which serves 17 households on average. Normally, precipitation in the study area follows the 24 solar terms of the Chinese calendar. The WHPIS managers have considerable experience in water control, and can balance water supply and demand. Thus, farmers can obtain sufficient water at a low cost.

3.2. Governance structure and social capital

This study focuses on the system level (the WHPIS). For 50 years, the irrigators are limited to villagers and family members living inside the village. The WHPIS has been collectively and informally managed by the irrigation community. The village cadre overlaps with the managers of the irrigation community and family leaders. Therefore, the governance of the WHPIS is featured with an interweaving structure of lineage, village, and irrigation community.

The Zeng family is a broader social organization composed of many households. These households share the same ancestors, but have different degrees of blood relationships (Freedman 1958). Most of the family members live in Zehe, while the rest have moved to other areas to engage in various professions, including the civil service (Faure 2007). Therefore, the irrigation community has a close relationship with the local government.

Family lineage is accompanied by family events, which provide an opportunity for water users, community leaders, the village cadre, and local officials to communicate and interact, and serve as platforms for the accumulation of social

capital. Family events are held monthly (on average) to celebrate traditional festivals or for weddings or funerals. One of the most important events is ancestral worship, which takes place in a family temple and is focused on the enhancement of spiritual beliefs. During these events, public affairs are also discussed, including the maintenance and operation of the WHPIS, thereby providing full information on collective activities related to irrigation management (Ostrom 2000).

This special governance structure contributes to strong social capital within the community in terms of reputation, reciprocity, and priority. Such capital is helpful for developing rules to coordinate behavioral expectations and providing incentives and penalties at a low cost. Reciprocity and priority encourage all participants to exchange information about the WHPIS and make decisions favoring collective benefits. Reputation can deter rule violating behaviors (water thieving or free-riding in relation to infrastructure maintenance) through strict punishment involving exclusion and isolation. Hence, there have been no cases of extreme water use or any need to take matters to court. Meanwhile, some local government officials are family members who often return to the village to attend these family events, which both parties use as a communication platform to interact, enabling the accumulation of substantial social capital. In this way, social capital incentivizes community leaders to seek external assistance and to internalize government interventions.

3.3. Sustainable governance of the WHPIS in the first stage

3.3.1. Rules

In general, the governance of an irrigation system includes two collective actions, namely, infrastructure provision and water use (Ostrom and Gardner 1993; Chai and Schoon 2016). Further, in relation to the WHPIS, water use is subdivided into water distribution and water appropriation. When engaged in these actions, the stakeholders' decisions often generate a range of conflicts (Wang et al. 2017); water appropriation conflicts among the irrigators, water distribution conflicts among the functions of irrigation, aquaculture, and pond protection, and infrastructure investment conflicts between the community and the local government. To resolve these conflicts, the WHPIS community has developed a number of rules, concerning the three types of collective actions.

3.3.1.1. Water distribution rule

The WHPIS provides water in response to three demands: irrigation, aquaculture, and protection of the pond bottom. Conflicts frequently arise among these three demands. The water distribution rule aims to ensure that the different demands can be coordinated and the conflicts resolved.

The water distribution rule is based on the sequence principle in terms of meeting different water demands: irrigating farmland has top priority, followed by feeding fish and securing the pond bottom. A water guard is responsible for water distribution via the operation of the stepped sluice gate. As an elder with strong sense of responsibility, he has a rich knowledge of changes in the amount

of available water, and is experienced in balancing water use among irrigation, fish feeding, and pond security.

When adjusting the water inside the pond, the water levels at steps I, III, and VI of the sluice gate are critical. The water level at step I (which represents 1/7 of the water inside the pond) is the lowest level. The water level should not fall below this point because it protects the pond bottom from cracking. The water level at step III (which represents 3/7 of the water inside the pond) is the lowest level required for fish feeding. The water level at step VI (which represents 6/7 of water inside the pond) is the warning line for pond security. That is, the water level should not rise above this point. When the water level rises over step VI, the excess water is released through a spillway to prevent it flowing directly over the dam wall and destroying it.

In times of drought, the guard manages to coordinate water demand for irrigation and aquaculture. For example, when rice plants are at the flowering stage, additional water equal to 3/7 of the pond's capacity is required to irrigate the farmland. If rainfall occurs to refill the pond, there will be sufficient water for aquaculture, otherwise; the fish farmer will suffer losses. The latter situation often occurs creating a challenging dilemma for the guard. Therefore, the guard needs to work hard to balance rainfall and water storage with the demands of irrigation and aquaculture.

In conditions of extreme drought, when rainfall is far from sufficient to irrigate all of the fields, a full pond of water could meet the demand for irrigating farmlands for one week as planned. In this situation, the guard needs to empty the pond for irrigation at the expense of aquaculture and pond bottom safety. However, in the rainy season, the water level often rises to the critical level and the guard needs to open the sluice gate in advance and inform farmers to block the intakes to their farmlands to avoid flooding.

3.3.1.2. Water appropriation rule

Regarding water appropriation, irrigators require a certain amount of water for irrigation and thus the challenge is how to balance the water requirements among the various irrigators. Therefore, the point of the water appropriation rule is to regulate the irrigators by specifying how much water each irrigator can take within a specific period.

Two crops are harvested each year. The first crop is grown from April to July, and the second from July to October. Each crop takes about 110 days to mature, 40 days of which require water from the WHPIS for irrigation. These 40 days cover five growing stages, namely, field flooding, seedlings, tilling, spike differentiation, and flowering. At each stage, the water needs to be 10 cm deep, which is sufficient for one week of growth. According to the criteria presented by Xia (1957), on average, one mu of farmland requires approximately 333.5 m³ of water. The water is most important in the flowering stage because it directly determines the production of paddy rice. Hence, any delay in supply or a lack of water will reduce output. This study focuses on the rules used at the flowering stage.

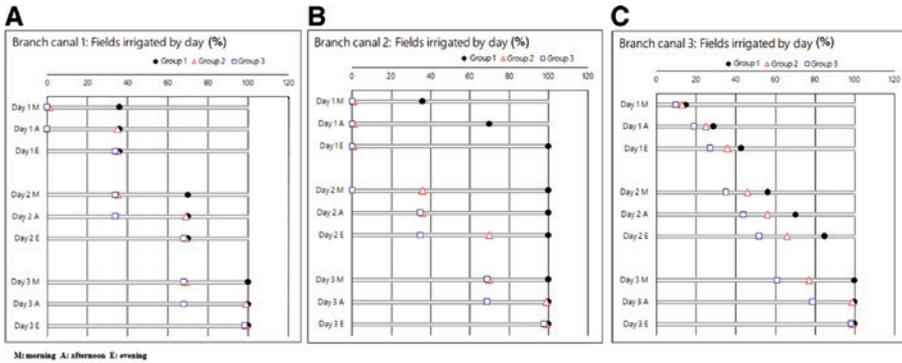


Figure 3: Water appropriation rules for the three WHPIS branch canals.

Three different water appropriation rules that were developed by the farmers are in force (see Figure 3), and have been operating for more than 50 years. The WHPIS has three branch canals, each of which has a specific water appropriation rule. Each branch serves 17 households, which are divided into three groups, called groups 1, 2, and 3, and are located upstream, midstream, and downstream, respectively. When taking water, a farmer uses a bag filled with sand to block the water from flowing along the canal, opens the intake to his farmland, and waits for the water to cover his plot to a depth of 10 cm.

- **Rotation rule for branch 1**
 During a three-day irrigation cycle, groups 1, 2, and 3 take water in the morning, the afternoon, and the evening, respectively. During the morning of day 1, group 1 takes water along the canal and leaves at noon for lunch. During the afternoon of day 1, group 2 arrives and diverts the water to their fields. When evening falls, they stop irrigating and return home before group 3 arrives to take their turn. In this way, after day 1, all of the groups have received similar amounts of water and have irrigated about 33% of their farmlands (see Figure 3A). They repeat this process on days 2 and 3 because it takes three days to fully irrigate all the fields. The rotation rules for branch canal 1 were established because most of the water appropriators are women who often work together and communicate frequently. As active cooperators, these women collectively designed the rotation rule and enforce it very well.
- **Semi-rotation rule for branch 2**
 Figure 3B shows that group 1 has absolute priority and takes all of day 1 to appropriate water, receiving sufficient water to irrigate 100% its farmlands by the end of day 1. Groups 2 and 3 then take water following the rotation rule over the next two days. Group 2 receives water in the morning and evening of day 2, as well as in the afternoon of day 3. Group 3 appropriates water on the afternoon of day 2, and in the morning and

evening of day 3. The survey found that this rotation rule was established after conflict between groups 2 and 3. While group 3 accepts that group 1 has priority access to the water and can wait until day 2 to irrigate their fields, they cannot tolerate waiting until day 3 to irrigate because such a delay would substantially reduce their crop production. The survey interviews revealed that the households in branch 2 are passive cooperators. Because most of the farmers in group 3 are relatively old, they have the advantage of being respected, and found it easy to obtain approval when asking group 2 to accept the rotation rule.

- **Jungle-water appropriation rule for branch 3**
All groups take water from branch canal 3 at the same time over three days. Because of its advantageous position, group 1 receives more water and takes less time to irrigate their farmlands than the other groups (see Figure 3C). The farmers in this branch canal are of similar gender and age, with equal social status and negotiating power. Thus, they formed a rule whereby they could all take water at the same time.

Generally, under the three rules outlined above, all of the groups ultimately receive similar amounts of water and can meet their crops' demands. This equilibrium result, which was formed through repeated long-term games, has been in operation for 50 years. The interviews revealed that these three water appropriation rules do not cause any significant differences in terms of the amount of water received. They all work to coordinate the farmers' expectations, and on average, 500 kg/mu of paddy rice is harvested from each crop. However, there are two variations in relation to the three rules. One relates to the time used for irrigation and the other to irrigation speed. Under the rotation rule, all groups take water at a similar time and speed. Under the semi-rotation rule, group 1 takes water one day earlier than the other groups. Under the jungle-water appropriation rule, all groups take water over the longest time period, although their farmlands are irrigated at similar speeds.

3.3.1.3. Investment and maintenance rule

The irrigation community has a rich history of infrastructure provision, and the rule governing infrastructure provision is mainly used to incentivize participants to offer appropriate efforts in relation to investment and maintenance.

The investment rule includes both regular investment and special investment. Regular investment is used for minor repairs to the WHPIS and is financed by the village, coming mainly from the rent of 15,000 yuan paid by the fish farming contractor. Farmers are not required to contribute either money or labor. Because the WHPIS was simply constructed using basic techniques, this investment amount is sufficient for annual minor repairs that keep the WHPIS running effectively. Special investments are used to update the WHPIS, which requires large amounts of capital. Zehe cannot afford this, and must obtain a subsidy from the local government. It takes close to six months for the village to obtain a government subsidy, which is limited to 10,000–20,000 yuan.

The WHPIS has two maintenance rules based on expenditure thresholds. The first rule concerns routine repairs which defines the scope of the repairs and includes canal upkeep, grass cutting, and silt removal. The community is responsible for these jobs, and it hires farmers to perform the necessary work twice a year. The work takes 4–5 days and the farmers are paid 50 yuan per day. A further 4–5 days of urgent repairs are often required after a storm during the rainy season.

The second rule concerns significant maintenance, which has no fixed budget, being dependent on the government subsidy. Hence, the village cannot create a fixed rule because of the uncertainty surrounding the funding. Once the village receives the subsidy, it contracts the maintenance work out to a construction company. The village cadre is responsible for a range of decisions including project design, planning, and work criteria, whereby the maintenance work meets local requirements and is of good quality at low cost.

The interviews revealed that the farmers were satisfied with the current maintenance effort. They stated that the WHPIS operated well and did not require extra maintenance such as lining. For example, leaving some silt inside the canal and the mouse holes is seen as being beneficial to the system rather than a problem, and thus they do not aim to remove all the silt or fill the mouse holes. There are two reasons for this. First, silt left inside the earthen canals helps to strengthen the canals and prevent them from collapse when there are fast-moving or large volumes of water. Second, mouse holes provide natural drainage that can protect the canals from flooding in the rainy season. Furthermore, the seepage caused by mouse holes is not regarded as a big problem because they can easily be filled with stones.

3.3.2. Sustainable governance

This study investigated farmers' perceptions regarding the WHPIS's performance. The farmers who were interviewed provided a number of positive evaluations regarding various matters including sufficient water supply, no farmland needing to be abandoned, satisfactory facility maintenance, equal water amounts for upstream and downstream areas, and lack of conflict among water users.

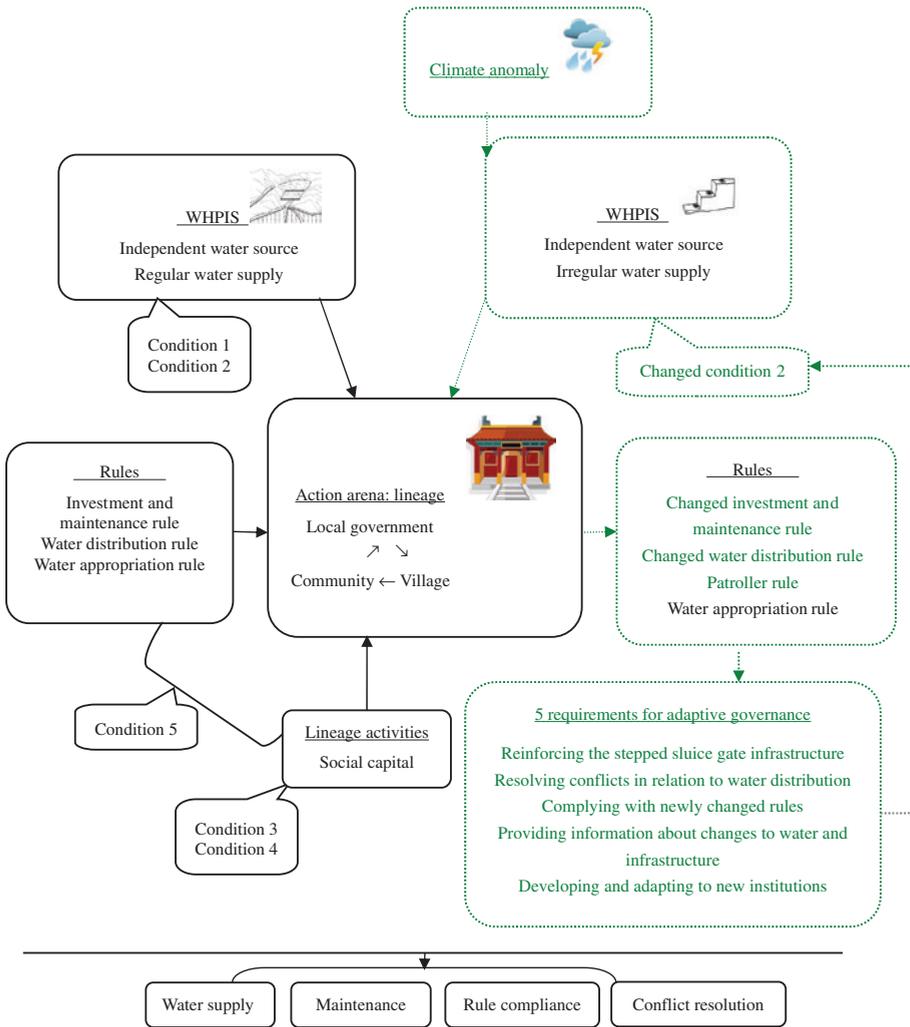
The main reason for the long-lasting effective governance of the WHPIS is that the established rules ensure infrastructure provision, access to water, and conflict resolution. Furthermore, social capital has encouraged the community to form a range of rules via family links. Social capital can incentivize rule-complying behaviors and deter rule-violating behaviors at a low cost; that is, participants follow the rules, which are implemented effectively.

4. Adaptive governance of the WHPIS in the second stage

4.1. Climate anomaly and changes to self-governance conditions

The sustainable governance of the WHPIS in the first stage has been achieved by meeting the five conditions of self-governance proposed by Dietz et al. (2003).

First, the WHPIS has an independent water source, a pond with a water storage function, meaning that water use can easily be monitored. In addition, the study



- Condition 1: The WHPIS has an independent water source, the pond, whereby water use can easily be monitored.
- Condition 2: The study area enjoys regular rainfall, moderate change in water users size, technology, the economy and social conditions.
- Condition 3: The lineage activities provide opportunities for the WHPIS community to communicate and establish strong social network.
- Condition 4: Water users are limited to the villagers in Zehe so as to easily exclude outsiders' access to the WHPIS.
- Condition 5: Through social capital, the set of rules is easily complied with and enforced.
- Changed condition 2: The climate anomaly changed the regularity of rainfall and water storage in the pond.

Figure 4: The adaptive governance process for the WHPIS.

area enjoys regular rainfall and follows the 24 solar terms of the Chinese calendar, which enables accurate prediction of weather changes. Traditional agricultural technology has been used for years, and these practices meet conditions 1 and 2. Next, family events ensure frequent communication, form strong social capital, and enable low-cost promotion of rule enforcement. Moreover, water users are limited to villagers. Hence, the WHPIS excludes outsiders without cost. These practices meet conditions 3 and 4. Using social capital, the set of rules designed by the irrigation community is easily complied with and enforced, which meets condition 5. As can be seen from Figure 4, the left side (in black) indicates that the five original conditions of the WHPIS match the effective governance criteria suggested by Dietz et al. (2003).

In the second stage, the emergence of a climate anomaly interrupted the stability enjoyed by the WHPIS in the first stage, causing condition 2 to change. As this survey shows since 2014, the weather has differed from that experienced in previous years. In June, the number of days that saw severe storms with precipitation of more than 10 mm/day increased from 3 days to 8 days. The additional five days of intense rainfall were difficult to predict and caused flooding and serious associated problems. The climate anomaly not only changed the regularity of water storage in the pond, but also increased the burden on the stepped sluice gate, increasing the risk of dam collapse. As a result, infrastructure maintenance and water-use coordination became more difficult to address.

4.2. Adaptive governance and institutional change

To sustain the water supply function of the WHPIS, the community, which could not afford to manage the climate anomaly, had to seek help from the local government. When local officials returned to the village to participate in family events, the community advised them of the damage the WHPIS could suffer in a severe storm. They emphasized that if the dam collapsed, the fields below it, as well as the lives of the whole village, would be in danger. The possible aftermath of the climate anomaly was such a significant threat that the local government agreed to provide assistance, and the two parties worked together to develop a new patroller rule. Accordingly, the community changed its investment, maintenance, and water distribution rules.

The first change concerned the patroller rule.² To obtain timely information about the changes in water level and infrastructure, the village and the irrigation agency of the local government co-created a new patroller rule. This was set as a formal rule issued by the local government. A patroller was recruited from the villagers and paid 3000 yuan a year, with the village and the local government

² The interviews revealed that the community had other choices in terms of an adaptation strategy besides designing the patroller rule, for example, reinforcing the dam with concrete. However, this would have required an investment of at least 200,000 yuan. After negotiation with the local government and after comparing the cost with that of a patroller of just 3000 yuan a year, the community decided to choose the latter approach.

paying half each. The patroller's responsibilities include inspecting the water level and checking the status of the dam, sluice gate, and spillway. Normally, the patroller checks the area eight times per month, but in the rainy season this increases to two times per day. The patroller records relevant information in a notebook and reports back to the community and the local government. If he identifies an emergent situation that could result in potential disaster, he alerts the village in the first instance using a bronze gong.

Regarding the changed investment rule, the local government decided to turn the intermittent subsidies of 10,000–20,000 yuan into a regular grant to Zehe. These funds are largely used to maintain the WHPIS facilities with the aim of removing any potential danger. This change to the investment rule has reduced the time needed to obtain the subsidy and ensures its regular arrival. Thus, these changes have enabled significant savings in terms of lobbying costs.

The maintenance rule was also revised. The original routine repair program has not been changed, but special repairs are now classified as routine and are institutionalized. Further, the community decided to reinforce the stepped sluice gate using modern techniques. Obviously, the maintenance plan was a bottom-up plan; the community leaders made decisions regarding size, budget, criteria, and time frame. Before starting construction, the community leaders worked with the builder to determine the project plans and criteria. In principle, maintenance is generally concerned with improving the existing facility rather than building a new structure. For example, work to strengthen the stepped sluice gate involved improvements to the existing structure instead of changing its length, width, and height. The project plans had to be changed when they were found to be incompatible with local needs. Subsequently, with the full participation of community leaders, the construction met local needs. Now, in the event of a heavy storm, the WHPIS can drain water without any seepage or blockages. The efforts of the community leaders achieved this high-quality level of maintenance.

Changes were also made to the water distribution rule. The revised rule prioritizes the WHPIS's security, followed by irrigation requirements and aquaculture needs. It also regulates the volume of water that needs to be drained from the pond before the May and June storms. Because its water control is effective, the WHPIS has been operating safely without any major disasters. For example, when a severe storm occurred on 20 May, 2015, the flood-water drained out through the spillway and the WHPIS continued to operate as usual.

4.3. New rules and conditions met

The changes to the abovementioned rules demonstrate the process of adaptive governance. These revised rules are intended to meet changes in condition 2 via the following five measures (see the right-hand side of Figure 4 (in green)).

Measure 1: reinforcing the stepped sluice gate and undertaking appropriate maintenance via the revised investment and maintenance rules. Because flooding resulting from a climate anomaly can potentially destroy the stepped sluice gate,

the first task was to strengthen this structure. The strengthening work was conducted using special concrete that was stronger than the concrete that is traditionally used. This work required a moderate amount of capital, which the community was able to provide. The modernized stepped sluice gate solved the seepage problem and can now drain water rapidly, even in a severe storm. The risk of dam collapse has been mitigated, the water level can be controlled, and the adaptive resilience of the system has been improved. The updated sluice gate can now be used for water discharge and ensures that the three water appropriation rules remain workable. Furthermore, through frequent interaction with the community, the local government has obtained greater local knowledge and has been able to create a more effective policy.

Measure 2: resolving conflicts in relation to water distribution. The amended water distribution rule states that the protection of lives now has priority over the economic benefits of irrigation and aquaculture. Because life security is one of the important criteria for evaluating the performance of the village cadre, a disaster caused by an unsafe pond will threaten their political careers. Draining some of the pond water before a severe storm will ensure pond security. Although discharging water in advance may result in some losses in relation to aquaculture, it can reduce the overall losses, because all of the fish will be lost if the dam collapses. Recently, the fish farmer has been participating in water discharge prior to the rainy season by liaising with community leaders regarding the amount of water drainage. In this way, pond security is ensured and fish farming losses are minimized.

Measure 3: complying with newly changed rules. Family ties and events provide strong social capital for participants to work together on the rules to ensure that they are accepted and followed. The revised rules relating to investment, maintenance, and water distribution are all enforced, and the embedded social capital can reduce rule-violating behavior. Although the new patroller rule is enforced by the local government through job instructions, the patroller's behavior is monitored via reports and electronic information such as real-time pictures and videos distributed via WeChat. These arrangements can deliver information efficiently and can monitor the patroller's behavior at a low cost. If any rule-violating behavior (e.g. lying or deceit) is discovered, the patroller will be fired and he will lose both his wages and his social benefits such as his reputation. These potential losses provide a strong deterrent, discouraging the patroller from engaging in any inappropriate behavior.

Measure 4: providing information about changes to water resources and infrastructure. First, the patroller rule clearly states that pond security should be the top priority. It strongly emphasizes the potential damage that can be caused by a severe storm and the importance of security for both the farmlands and villagers. Second, the patroller rule provides information about the changes in infrastructure and the water level. This information is important in enabling the community to make appropriate decisions in relation to water distribution to reduce disagreements between those pursuing either irrigation or aquaculture. Finally,

the patroller is a key link between the community and the local government. His work provides the basis for the local government's inspections of the pond prior to providing funds for maintenance.

Measure 5: developing and adapting to new institutions. The community had to transform its various institutions to adapt to the emergent changes caused by the climate anomaly. Obviously, the process of institutional change occurred from the bottom-up. What is more important is that the institutional change was incremental. Only some of the rules were changed while the remaining rule, the water appropriation rule, remained unchanged.

4.4. The effect of adaptive governance

The evaluation of adaptive governance in the second stage is based on the perceptions of both water users and community leaders. Two additional evaluation criteria -flooding discharge and water-related disaster in the second stage-are added to the first-stage criteria. Water users provided positive evaluations, stating that they received sufficient water under the new governance measures and that this was similar to the amount received in the first stage. There were no instances of disasters in severe storm situations because of the implementation of timely and effective measures. In May and June, farmers were alerted on several occasions to open the water intakes into their fields to discharge surplus water. Crop production was not reduced and the usual level of output was maintained. Furthermore, the production of paddy rice between upstream and downstream areas is similar, averaging about 500 kg/mu. In addition, the new water distribution rule has ensured that any potential aquaculture loss in a severe storm can be minimized and that the fish farmer continues to pay a pond contract fee. Obviously, the climate anomaly has not had a significant impact on water users because the WHPIS has continued to meet their water demands. In addition, the water appropriation rule has not changed, and is still in use.

The community leaders were very satisfied with these measures. First, the effort needed to lobby the local government for funds has been reduced under the new investment rule. The new rule institutionalizes funds for irrigation maintenance, and these funds are now provided as a regular subsidy rather than as occasional assistance. These routine funds encourage the community to maintain the WHPIS through appropriate and regular upkeep. In addition, the community considered that the local government acted appropriately in that they provided designated funds to ensure the continuous safety of the WHPIS. Second, the patroller rule meets the requirement to accurately monitor any changes in the WHPIS. The village urgently required the funds necessary to hire a professional patroller. This problem has been fully resolved by the allocation of funds from the local government. This rule has also formalized the provision of information about the WHPIS.

In general, based on the abovementioned effects of governing the WHPIS, the system has achieved a new level of stability. Furthermore, the multiple

participants including the village, the irrigation community, and the local government are enjoying a new balance in their relationships and social capital has been strengthened as a result of kinship and family events. The community has learned a lot from the process of adaptive governance and has increased its capability in terms of self-governance.

5. Discussion

This study describes two stages of WHPIS governance; one is sustainable long-term governance, and the other is adaptive governance under a climate anomaly. Based on this case study, the issues raised in the Introduction section are discussed.

5.1. Social capital and self-governance

The two stages of WHPIS governance illustrate the long-lasting nature of the relevant institutions and their incremental change. More importantly, the critical function of social capital is revealed. Social capital, in the form of reputation, reciprocity, and priority, encourages communities to meet the five conditions proposed by Dietz et al. (2003) to achieve successful self-governance through developing effective institutional arrangements. This viewpoint is consistent with the statement by Meinzen-Dick (2007) that social capital matters in irrigation management. Social capital provides principles for designing, monitoring, and implementing rules and deters rule violators at a low cost. Family events provide an arena for the irrigation community, the village cadre, and government officials to interact, enabling social capital to be maintained and strengthened. In line with a statement by Ostrom (2000), the establishment of trust in these three entities enables participants to develop rules and to resolve the dilemmas of irrigation governance.

This case demonstrates an example of agricultural water use and social capital maintenance at the community level in southern China. Although the rural regions in Guangdong are suffering from the problem of labor emigration caused by rapid industrialization and urbanization, the level of social capital has not been significantly affected because labor emigration in the region is characterized by migrant farmers going out to work in cities within Guangdong rather than other provinces. Hence, with convenient transport available, these migrants often return to their home community to attend family activities. In this way, a high level of social capital both within the community and in partnership with the local government has been maintained by the farmers.

5.2. Institutional change and adaptive governance

The stage of adaptive governance provides insight into the process of institutional change in response to climate disturbance. The occurrence of a climate anomaly resulted in a change to condition 2 that could not have been managed under the old institutional arrangements. This process, as Dietz et al. (2003) suggested, requires

new rules to be created to address changed conditions. Based on social capital, the community revised three rules and designed a new rule to meet the requirements of condition 2. In particular, with the support of the local government in the form of a subsidy, the community adapted the WHPIS to a climate anomaly via self-governance. This solution is consistent with the viewpoint presented by Janssen et al. (2007) that institutional and technical measures can be combined to develop rules to sustain the commons. However, the result contradicts with the findings of robustness studies (Anderies 2006; Nelson et al. 2010) suggesting that maladaptation or a trade-off effect will occur because of the disintegration of social capital within the community (Schoon et al. 2011). In this case study, the government subsidy reinforced the local coordination system formed by the community rather than destroying it.

The local government officials maintain connection with the community via family events. This interaction reinforces the link between the infrastructure provider and users noted by Anderies et al. (2004). This is similar to the function of Balinese temple priests, the infrastructure provider, and the family members of water users, as proposed by Lansing (1991). Regarding the WHPIS, government officials are subsidy providers and also family members. This dual identity supports close interactions between infrastructure providers and resource users, ensures that infrastructure provision matches local requirements, and increases system robustness through adaptive self-governance. The institutional changes outlined here have not resulted in maladaptation of the WHPIS or any loss to the community. A synergetic process has emerged instead of a trade-off.³

The incremental change in institutions has increased the robustness and efficiency of the WHPIS. Institutional change has occurred largely via the revision of three rules and the addition of one new rule. Consistent with the finding of Araral (2013b) that physical geography determines institutional choices, the geographical feature of the WHPIS has framed a broader water governance regime, which in turn has defined the changing scope of effective rules. In line with this logic, adaptive governance in response to a climate anomaly demands nuanced institutional change rather than a major transformation. Additionally, of the rules that have been changed or introduced, it is only the patroller rule that has involved an extra cost. In summary, the incremental change in the institutions is highly efficient. This finding concurs with the proposals by Dietz et al. (2003) and Nelson et al. (2007) that incremental adjustments to climate change involve rapid and short-term responses. The course of adjustment demonstrates capacity building and learning about how to deal with unexpected events, and supports the establishment of flexible institutions instead of traditional management. As this case study shows, the community increased its capability in terms of lobbying the local

³ According to the categories of trade-offs presented by Lam and Chiu (2016), one type of trade-off is between control and flexibility, while the other is among specific dimensions of system performance. In this study there is little evidence of any trade-offs occurring as a result of the adaptive governance of the WHPIS.

government to invest in infrastructure and its capability in terms of autonomy through internalizing the local government intervention.

5.3. System robustness

By moving one step forward, this study shows how a community-based irrigation system actively sought support from the local government to deal with climate disturbance. Strong social capital enabled incremental changes in local institutions, resulting in improvements to the WHPIS to ensure a new level of stability. Family events enable social capital within the community and in partnership with the local government to be sustained over the long term. Consistent with the viewpoint of Murtinho et al. (2013), external support from the local government driven by the community contributes to the adaption of the community to the climate anomaly. The findings of this study are also consistent with those of Lam and Chiu (2016), whereby a community with strong social capital can efficiently implement water use rules that are compatible with infrastructure provision, even after intervention by the local government.

This study reveals that autonomy lies at the core of the governance structure, ensuring that the irrigation system can continuously adapt to environmental change via institutional change based on social capital. This adaption process in turn increases the robustness of the WHPIS, including the capacity for self-organization and learning, as well as the ability to absorb change.

6. Conclusion

This study provides two nuanced contributions to the literature on adaptive governance of the commons in response to climate disturbance. First, it reveals the positive connection between social capital and adaptive governance in terms of institutions. The case study involving the WHPIS provides strong evidence that a community can collectively overcome problems, namely, infrastructure provision and water use, via institutional arrangements in such a way as to sustain the WHPIS for more than 50 years. In the event of climate disturbance, the community can adapt the WHPIS to meet environmental changes and achieve robustness through incremental institutional changes. The more appropriate the rules are to the irrigation system, the more effective the two types of governance are. This leads to sustainable/adaptive governance (including rule design/change) and numerous benefits from strong social capital both within the community and beyond. The stronger a community's social capital, the smoother the change and implementation of rules. Social capital can be maintained and strengthened via long-lasting and effective means such as family events wherein multiple participants interact frequently (see Figure 5). In general, a community with strong social capital can efficiently achieve sustainable and adaptive governance of the commons. This mechanism provides commons scholars with a pathway of "social capital-institutional change-adaptive governance" to sustainable agricultural water use, even in the context of rapid globalization.

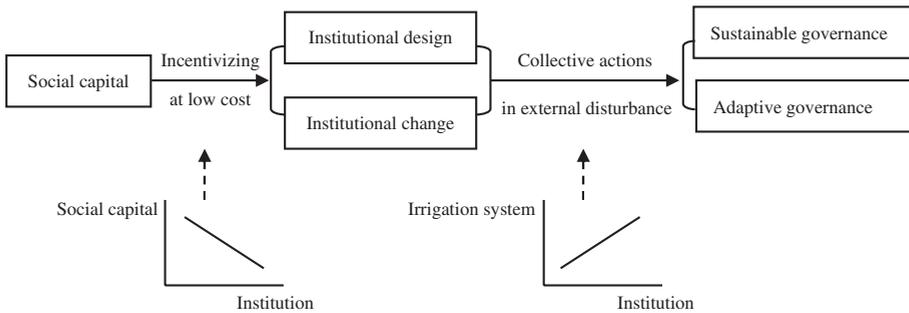


Figure 5: Relationship between social capital and governance of the commons.

Second, this study adds to the international pool of successful approaches to climate adaptation and commons sustainability. It emphasizes that China has employed self-governing irrigation systems for a long time. These systems, managed by the community, feature an independent water source at the village level, strong social capital stemming from lineage activities, flexibility of local institutions, and capacity building through self-learning and interactions with external parties. The operation of the WHPIs provides new evidence for scholars studying adaptive governance and lessons for communities and policy-makers regarding appropriate actions in response to climate change.

Literature cited

- Agrawal, A. 2008. The Role of Local Institutions in Adaptation to Climate Change. In *Papers of the Social Dimensions of Climate Change Workshop*. The World Bank, Washington DC, March 5–6.
- Aligica, P. D. and V. Tarko. 2014. Institutional Resilience and Economic Systems: Lessons from Elinor Ostrom's Work. *Comparative Economic Studies* 56(1):52–76.
- Anderies, J. M. 2006. Robustness, Institutions, and Large-scale Change in Social-Ecological Systems: The Hohokam of the Phoenix Basin. *Journal of Institutional Economics* 2(2):133–155.
- Anderies, J. M., M. A. Janssen, and E. Ostrom. 2004. A Framework to Analyze the Robustness of Socioecological Systems from an Institutional Perspective. *Ecology and Society* 9:18.
- Araral, E. 2013a. What Makes Socio-ecological Systems Robust? An Institutional Analysis of the 2000 Year-old Ifugao Society. *Human Ecology* 41:859–870.
- Araral, E. 2013b. Does Geography Matter to Institutional Choice? A Comparative Study of Ancient Commons. *Geoforum* 44:224–231.
- Bastakoti, R. C. and G. P. Shivakoti. 2012. Rules and Collective Action: An Institutional Analysis of the Performance of Irrigation Systems in Nepal. *Journal of Institutional Economics* 8(2):225–246.

- Cárdenas, J. C., J. Stranlund, and C. Willis. 2000. Local Environmental Control and Institutional Crowding-out. *World Development* 28(10):1719–1733.
- Cárdenas, J. C., M. A. Janssen, M. Ale, R. Bastakoti, A. Bernal, J. Chalermphol, Y. Gong, H. Shin, G. Shivakoti, Y. Wang, and J. M. Anderies. 2017. Fragility of the Provision of Local Public Goods to Private and Collective Risks. *Proceedings of the National Academy of Sciences* 114(5):921–925.
- Chai, Y. and M. Schoon. 2016. Institutions and Government Efficiency: Decentralized Irrigation Management in China. *International Journal of the Commons* 10(1):21–44.
- Cifdaloz, O., A. Regmi, J. M. Anderies, and A. Rodriguez. 2010. Robustness, Vulnerability, and Adaptive Capacity in Small-Scale Social-Ecological Systems: The Pampa Irrigation System in Nepal. *Ecology and Society* 15:39.
- De Fraiture, C., G. N. Kouali, H. Sally, and P. Kabre. 2014. Pirates or Pioneers?: Unplanned Irrigation around Small Reservoirs in Burkina Faso. *Agricultural Water Management* 131:212–220.
- Dietz, T., E. Ostrom, and P. C. Stern. 2003. The Struggle to Govern the Commons. *Science* 302(5652):1900–1912.
- Fabricius, C. and S. Collins. 2007. Community-based Natural Resource Management: Governing the Commons. *Water Policy* 9(2):83–97.
- Faure, D. 2007. *Emperor and Ancestor: State and Lineage in South China*. Stanford, CA: Stanford University Press.
- Freedman, M. 1958. *Lineage Organization in Southeastern China*. London: University of London, Athlone Press.
- Huang, Q. 2014. Impact Evaluation of the Irrigation Management Reform in Northern China. *Water Resources Research* 50(5):4323–4340.
- Janssen, M. A., J. M. Anderies, and E. Ostrom. 2007. Robustness of Social-Ecological Systems to Spatial and Temporal Variability. *Society & Natural Resources* 20(4):307–322.
- Lam, W. F. and C. Y. Chiu. 2016. Institutional Nesting and Robustness of Self-Governance: The Adaptation of Irrigation Systems in Taiwan. *International Journal of the Commons* 10(2):953–981.
- Lansing, J. S. 1991. *Priests and Programmers: Technologies of Power in the Engineered Landscape of Bali*. Princeton, NJ, USA: Princeton University Press.
- Meinzen-Dick, R. 2007. Beyond Panaceas in Water Institutions. *Proceedings of the National Academy of Sciences* 104(39):15200–15205.
- Murtinho, F., H. Eakin, D. López-Carr, and T. M. Hayes. 2013. Does External Funding Help Adaptation? Evidence from Community-based Water Management in the Colombian Andes. *Environmental Management* 52:1103–1114.
- Nelson, D. R., W. N. Adger, and K. Brown. 2007. Adaptation to Environmental Change: Contributions of a Resilience Framework. *Annual Review of Environment and Resources* 32(1):395–419.
- Nelson, M. C., K. Kintigh, D. R. Abbott, and J. M. Anderies. 2010. The Cross-Scale Interplay between Social and Biophysical Context and the Vulnerability

- of Irrigation-dependent Societies: Archaeology's longterm perspective. *Ecology and Society* 15(3):31.
- Ostrom, E. 1990. *Governing the Commons: The Evolution of Institutions for Collective Action*. New York: Cambridge University Press.
- Ostrom, E. 2000. Social Capital: A Fad or a Fundamental Concept? In *Social Capital: A Multifaceted Perspective*, eds. P. Dasgupta and I. Serageldin, 172–214. Washington, DC: World Bank.
- Ostrom, E. and R. Gardner. 1993. Coping with Asymmetries in the Commons: Self-Governing Irrigation Systems can Work. *Journal of Economic Perspectives* 7(4):93–112.
- Pérez, I., M. A. Janssen, A. Tenza, A. Giménez, A. Pedreño, and M. Giménez. 2011. Resource Intruders and Robustness of Social-ecological Systems: An Irrigation System of Southeast Spain, a Case Study. *International Journal of the Commons* 5(2):410–432.
- Roggero, M., A. Bisaro, and S. Villamayor-Tomas. 2018. Institutions, Climate Adaptation and the IAD Framework: A Systematic Review. *Journal of Institutional Economics* 14:423–448.
- Schoon, M. and M. Cox. 2012. Understanding Disturbances and Responses in Social-Ecological Systems. *Society & Natural Resources* 25(2):141–155.
- Schoon, M., C. Fabricius, J. M. Anderies, and M. Nelson. 2011. Synthesis: Vulnerability, Traps, and Transformations – Long-Term Perspectives from Archaeology. *Ecology and Society* 16(2):24.
- Schultz, L., C. Folke, H. Osterblom, and P. Olsson. 2015. Adaptive Governance, Ecosystem Management, and Natural Capital. *Proceedings of the National Academy of Sciences* 112(24):7369–7374.
- Tang, S. 1992. *Institutions and Collective Action: Self-Governance in Irrigation*. San Francisco, CA: ICS Press.
- Thapa, B., C. Scott, P. Wester, and R. Varady. 2016. Towards Characterizing the Adaptive Capacity of Farmer-Managed Irrigation Systems: Learnings from Nepal. *Current Opinion in Environmental Sustainability* 21:37–44.
- Villamayor-Tomas, S. 2017. Disturbance Features, Coordination and Cooperation: An Institutional Economics Analysis of Adaptations in the Spanish Irrigation Sector. *Journal of Institutional Economics* 14:501–526.
- Vollan, B. 2008. Socio-Ecological Explanations for Crowding-out Effects from Economic Field Experiments in Southern Africa. *Ecological Economics* 67(4):560–573.
- Wang, J. X., Z. G. Xu, J. K. Huang, and S. Rozelle. 2006. Incentives to Managers and Participation of Farmers: Which Matters for Water Management Reform in China? *Agricultural Economics* 34(3):315–330.
- Wang, Y. H., C. L. Chen, and E. Araral. 2016. The Effects of Migration on Collective Action in the Commons: Evidence from Rural China. *World Development* 88:79–93.
- Wang, R. Y., C. N. Ng, J. H. Lenzer Jr., H. Dang, T. Liu, and S. Yao. 2017. Unpacking Water Conflicts: A Reinterpretation of Coordination Problems in

- China's Water-governance System. *International Journal of Water Resources Development* 33(4):553–569.
- Wittfogel, K. A. 1957. *Oriental Despotism. A Comparative Study of Total Power*. New Haven: Yale University Press.
- World Bank. 2007. *Emerging Public-private Partnership in Irrigation and Drainage Management*. Water Sector Board Discussion Paper Series, paper no. 10.
- Xia, C. X. 1957. *How to Build Ponds and Reservoirs*. Guiyang: Guizhou People's Press. (In Chinese).
- Yu, X. M., Y. Geng, P. Heck, and B. Xue. 2005. A Review of China's Rural Water Management. *Sustainability* 7(5):5773–5792.
- Yu, D. J., M. R. Qubbaj, R. Munepeerakul, J. M. Anderies, and R. M. Aggarwal. 2015. Effect of Infrastructure Design on Commons Dilemmas in Social-ecological System Dynamics. *Proceedings of the National Academy of Sciences* 112(43):13207–13212.
- Zhang, L., N. Heerink, L. Dries, and X. P. Shi. 2013. Water Users Associations and Irrigation Water Productivity in Northern China. *Ecological Economics* 95(11):128–136.