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INSTITUTIONAL EVOLUTION AND SOCIAL-ECOLOGICAL RESILIENCE: A STUDY OF IRRIGATION INSTITUTIONS IN TAIWAN

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Abstract

Taiwan's irrigation management has faced a series of challenges in the past decades. As the country's economy developed, agriculture has ceased to be a viable economic activity; the decline of agriculture has in turn adversely affected the incentives of farmers and the government to engage in irrigation management. Despite these challenges, the evolution of Taiwan's irrigation systems in the past decades has been characterized by a high degree of resilience. Although irrigation management is unlike that in the good old days when farmers actively engaged in meticulous management and were willing to contribute significant manual and monetary resources, farmers' organizing abilities and social capital accumulated over the years have largely retained, and continued to sustain a vibrant management order. The general picture is that while the sector as a whole has been in flux and gone through many changes, the vibrancy of the system remains.

Drawing upon the literature of complexity studies and conceptualizing an irrigation system as a social-ecological system (SES), this paper seeks to explain and understand the institutional vibrancy and resilience of Taiwanese irrigation. The major argument is that the design of Taiwan's irrigation institutions, as a result of years of trial and error, has been able to cope with the dynamics inherent in the SES. The institutions allow various actors and organizations at different levels to engage in continuous learning and adaptation. I shall examine how disturbances of different types have impact the structure and dynamics of the Taiwanese system, how individuals and organizations at different levels have responded to the disturbances, and how these responses have constituted the systemic response to the changing environment.

Institutional Evolution and Socio-ecological Resilience: A Study of Irrigation Institutions in Taiwan

Wai Fung Lam

Resilience amid Change in Taiwanese Irrigation

Taiwan's irrigation management has been facing a series of challenges in the last decades. As the country industrialized, agriculture has lost its comparative advantage and become economically non-viable. The over-production of paddy rice in Taiwan and worldwide has continued to keep the grain prices low; the opening up of Taiwan's agricultural produce market to international competition as a result of Taiwan's entry to the WTO is going to make agriculture even more difficult to sustain (AERC, 1999, 2000). The decline of agriculture has also brought about significant changes to the social context in which irrigation operates. As the rural youth leave for cities to find better jobs, the farming population is ageing rapidly.[1] All these social economic changes have adversely affected agriculture and rural infrastructure management. At the national level, the decline of agriculture has given rise to the debates on the effective utilization of the country's water resource across different economic sectors.

Yet unlike in many other Asian countries where farming was simply abandoned in the process of industrialization, the agricultural sector in Taiwan remains relatively intact. Back in the 1990s, Williams (1994) observed that, "the statistically much diminished role of agriculture is belied, though, by the physical impression conveyed by the rural landscape. Traveling through the lush green countryside of Taiwan, one is impressed by the extraordinary degree of human occupancy… It is an intensely green and vivid landscape that leaves a lasting impression, particularly for someone used to the spacious checkerboard pattern of the American Midwest." (p. 218). Williams's observation is still largely valid nowadays. In fact, while the number of farmers who actually engage in farming activities might have decreased, the number of farm households has remained relatively steady.[2] Taiwanese farmers have shown unwillingness to give up on farming or their lands[3]; in many instances, farmers still engage in farming despite it means losing money! Irrigation is largely in good order too. Irrigation infrastructure is relatively well maintained, largely due to continuous investments by government and local Irrigation Associations (IAs). Judging from the interviews with farmers during fieldwork, water distribution and allocation at the field level is also kept in good order. Although active voluntary labor can no longer be found, the social infrastructure that has evolved over years of cooperation has not deteriorated too badly. The close links between the Irrigation Associations and farmers are still relatively solid.

In 2000, while agriculture accounted for about 2% of Taiwan's GDP, it used up more than 78% of the country's available water resource (COA, 2003; JTIA, 2000).[4] As the economy develops and the domestic and industrial demands for water increase, the viability of the current distribution of water resource has been under constant challenge. So far the irrigation sector has been successful in fending off the demands for a transfer of water rights from agriculture to other sectors. In many instances, arrangements have been made to transfer the use, but not the rights, of water resource from the irrigation sector. An important question is how the dynamics underlying water resource management at the macro level affects the way farmers and irrigation institutions adapt to the changing environment.

The macro governance structure of Taiwan has also undergone drastic changes, which have had significant implications for irrigation management. Irrigation management is never a mere engineering or local issue. Particularly in Taiwan, agriculture and irrigation has a long history of government involvement, and in fact has been used as a tool by the government to govern the rural populace (Foster, 2001; Stavis, 1974). Since the transformation of the Taiwanese polity from an authoritarian regime to one of competitive party politics in the late 80s, politicians have not hesitated to exploit issues of agriculture and irrigation to advance their political interests. Politicization has generated uncertainty and shocks to the operation of the irrigation sector (Lam, 2004). Yet the sector as a whole has shown resilience to adapt to the change, and more importantly, to resist attempts of the central government to exert control. Unlike in other East Asian countries such as Japan and South Korea where the decline of agriculture has been accompanied by the nationalization of irrigation institutions, the irrigation sector of Taiwan is moving towards even higher degrees of self-governance and autonomy.

The evolution of Taiwan's irrigation systems in the last decades has shown a high degree of resilience.[5] While the decline of agriculture has to a certain extent reduced farmers' incentive to engage in agriculture and irrigation management, farmers and their irrigation institutions have been able to adapt to the new environment. What is the dynamic of the process of adaptation? What are the attributes of the system that enable it to adapt, and to transform itself into an even more resilient system? Drawing upon the literature of complexity studies and conceptualizing an irrigation system as a socio-ecological system (SES), this paper seeks to understand the institutional vibrancy and resilience of Taiwanese irrigation.

In the next section I shall first identify and discuss major changes in Taiwan's political economy of agriculture and irrigation in the past decades. These changes present significant challenges to irrigation management, and have become the key parameters of the context in which irrigation institutions operate and evolve. I shall then lay out the structure and dynamics of the irrigation system as a Social-Ecological System (SES), with particular reference to the specific features of Taiwanese irrigation. I shall show that the basic design of Taiwan's irrigation institutions, as a result of years of trial and error, has been able to cope with the dynamics inherent in the SES. The design allows various actors and organizations at different levels to engage in continuous learning and adaptation. I shall also discuss and examine how the macro disturbances have impact on Taiwan's irrigation, and how the system adapted and evolved in response to the changes.

The Political Economy of Irrigation in Taiwan: Disturbances and Challenges

One can easily find in any standard economics textbooks the model of economic development in a market economy. The model goes like this—as a market economy develops, agriculture will lose its comparative advantage vis-à-vis industrial and tertiary production. The change in relative values will generate incentives for economic actors to make adjustments in resource allocation; investment will flow from agriculture to more profitable activities. Very often a caveat is made, saying that such an adjustment process in the real world may not be as smooth as portrayed in the model. There are instances in which economic actors adjust badly, and are simply incapable or unwilling to make adjustments. Despite that, the general dynamic is that agriculture will be replaced by other economic activities until the marginal benefit of agriculture comes at par with that of other economic activities.

The trajectory of Taiwan's economic development is very different from the textbook model, however, largely due to the active role played by the Taiwanese government in steering the economic development process in the country (Amsden, 1988; Kuo and Liu, 1999; Liao, Huang, & Hsiao, 1986; Moore, 1993; Wade, 1990). In the 1950s and the 1960s, the government adopted policies to tax the agricultural sector to help launch industrialization. By a series of exploitative measures such as barter of fertilizer for rice and compulsory rice purchases, the government was able to extract surplus out of agriculture to support industrialization by providing affordable food and necessary financial transfers to the industrial sector. By the late 1970s, Taiwan's industry took off. Agriculture lost out in the process. Ironically, the efficiency of the agriculture sector (given a labor intensive mode of production) has made the sector particularly vulnerable to the process of industrialization. Taiwan's agriculture is dominated by paddy rice. The overproduction of paddy rice in Taiwan and worldwide, together with the decreasing demand for staple as a result of economic development, has put tremendous pressure on grain prices (Pingali et. al., 1997; Wu Huang, 1993). Since 1990, agriculture has accounted for less than 3% of the country's GDP.

While agriculture lost its economic viability, the kind of cross-sector reallocation of resources as described in standard economics texts did not occur in Taiwan. Understanding Taiwan's agriculture policy requires that one put the issue in the larger context of the country's political economy. Ever since its inception, the government in Taiwan has always been in a dormant but confronting relationship with the People's Republic of China (PRC). While Taiwanese government maintains that Taiwan is an independent political entity, the PRC considers it a renegade province to be united with the motherland. From the perspective of the Taiwanese government, a war across the Taiwan Strait is not only plausible but inevitable. National security has been a paramount concern that comes above other policy considerations (AERC, 1999, 2000; Williams, 1994). An implication is that food security is a key policy imperative underlying the formulation of agriculture policy in the country. To maintain food security, the Taiwanese government maintains a grain reserve that is sufficient for the consumption of the island's population for about a year. More importantly, the government is determined to ensure that the agricultural potential be preserved, so that Taiwan has the ability to feed its population in case of embargoes. To maintain the agricultural potential, the government has promulgated strict zoning laws, restricting changes of land use of paddy fields. To compensate the farmers, the government has provided a variety of subsidy programs, including guaranteed procurement of grains at preferential prices, subsidies for fallowing, and substantial rural infrastructure projects. As the vibrancy of irrigation infrastructure is essential to the maintenance of agricultural potential, the government has been subsidizing the irrigation sector quite substantially.[6]

Other than the food security concern, another aspect of the political economy of agricultural policy in Taiwan concerns with votes and elections. The rural populace in Taiwan constitutes a substantial voting block that no political parties in the country could afford to ignore. As of 2002, the 17 IAs in Taiwan have a total membership of more than 1.2 million (TJIA, 2003). Assuming that each member household has four people eligible to vote, the IAs can influence almost 5 million votes. Unlike in many other Asian countries, Taiwan's rural populace is highly organized, an unintended consequence of the government's effort to control the rural population through a network of semi-governmental organizations, including the IAs (Foster, 2001). When the interest of these organized groups is challenged, they won't hesitate to defend themselves.[7]

The government's food and agricultural policies would not have affected agriculture too adversely had the agricultural sector been able to diversify production. Unfortunately, the structure of Taiwan's agriculture is not conducive to diversification or change. A major structural problem is the small landholding size, which is largely a result of the land reforms so successfully implemented in the early 1950s. Since 1990, the average landholding size of farm households in Taiwan has been less than 1 hectare.[8] The small landholding size does not allow effective use of machines and, more importantly, renders infrastructure investment uneconomical. Farmers simply cannot make a living on farming.[9] As farming turns unprofitable, farmers in other countries might well sell their farmlands and move to cities. Taiwanese farmers, however, are generally unwilling to do so. Farmers' bond of land might explain part of the situation, but material incentive might be a more important factor. Many farmers expect that some day their lands might be rezoned, which would mean a substantial increase in land value. For farmers who derive a major part of income from non-farm activities, they could afford keeping the lands and wait.

The political economy of agriculture as described has impact on irrigation management at two levels. At the field level, farmers face little incentive to engage in irrigation management. Unlike in good old days when irrigation water very much determined farmers' income, and so farmers had strong incentives to get involved in irrigation operation and maintenance (O&M), farming nowadays is considered a supplementary economic activity which, in some circumstances, is not even for profit-making but simply for keeping the lands cultivable. Such a low-incentive mode of agriculture poses serious challenges to Taiwanese irrigation management which is grounded upon farmers' participation and farmer-government synergy.

At the sectoral level, the change has posed to the government the difficult question of how to restructure its relationship with the irrigation sector. Given that farmers are trapped in agriculture by government policies and do not have much incentive to invest in irrigation maintenance and operation, the government finds itself taking on an increasingly heavy role in irrigation management (AERC/IIMI, 1997; Chen, 1997; TJIA, 1992, 2003). Since 1993, the government has been paying membership fees to the IAs on farmers' behalf, in addition to the large infrastructure maintenance subsidy that also comes out of the government budget. As the irrigation sector is getting more and more reliant on government subsidy, the government feels obliged to impose tighter control to make sure that public monies are appropriately spent. Interestingly, that the government has put in increasing amounts of resources in the irrigation sector does not mean that all the IAs are facing financial difficulties. The IAs that are located near urban areas have in fact been accumulating much wealth through the sales of lands and properties that ceased to serve irrigation purposes (AERC, 2001). Because farmers are no longer enthusiastic about getting involved in irrigation management and hence the operation of the IAs, the government finds herself taking on the role of the monitor to prevent the IAs from turning into some private clubs of IA staffs and local politicians who control the IAs.

Despite the government's intention to tighten control, putting effective control in place is no easy task (CAEA, 1995). First, the IAs are formed and owned by farmers. It is not clear as to how the government could square the concept of private property with the process of nationalizing the IAs. Second, how to manage the IA staff is another thorny issue. Currently the IA staff do not have the civil servant status; in fact, the majority of the older generations of the staff have received only limited formal education. Third, the IAs are important political mobilization machines. Politicians who have a strong hold in these organizations are unlikely to give in easily.

Another dimension of the challenge at the sectoral level is concerned about water resource allocation and utilization across sectors. As agriculture is no longer a major economic activity, many people argue that water rights should be reconsidered so that more water could be diverted to domestic and industrial uses. To irrigation officials and the IAs, they need to address two issues. First, they need to provide justifications for their defense of their water rights. Second, they need to come up with policy recommendations that allow effective utilization and flexible allocation of water across sectors.

The challenges at both the operational and sectoral levels have impact on the operation and management of irrigation systems in Taiwan. To understand how the Taiwanese irrigation systems have responded to these challenges, and how their responses have constituted and affected the dynamics of the evolution of irrigation institutions, I shall draw upon the literature on complexity studies and social-ecological systems to highlight the dynamics involved and how the systems have coped with the dynamics.

Irrigation System as a Social-Ecological System

An irrigation system can be conceptualized as a complex social-ecological system (SES) in which human agents in different capacities and of different attributes engage in continuous interaction in response to one another and the biophysical environment (Anderies, Janssen, & Ostrom, 2003; Berkes & Folke, 1998; Berkes, Colding, & Folke, 2003). Interactions among human agents can give rise to emergent aggregate pattern and hence systemic attributes that determine the system's ability to adapt to the turbulent environment. Unlike other complex systems that do not involve humans, the potentials of human cogitation and strategic thinking further increase the level of complexity involved in a SES. A SES is complex, epistemic, hierarchic, and dynamic.

A Complex System

A complex system is constituted by a large number of autonomous units which constantly interact with one another, as well as the environment of which they are parts. In other words, a complex system has the process of self-organization built in. "Self-organization is a process in which pattern at the global level of a system emerges solely from numerous interactions among the lower-level components of the system. Moreover, the rules specifying interactions among the system's components are executed using only local information, without reference to the global pattern" (Camazine, et.al., 2001). A complex system is complex not because it involves a large number of units or rules; instead, complexity pertains to the emerging systemic patterns or properties that are not present at the unit level.

In a complex system, the process of aggregation of the behavior of individual units into systemic behavior is often non-linear and combinatorial, and hence non-trivial and hard to make point predictions. Trivial changes at the individual level could trigger off chains of effects leading to substantive transformation at the systemic level, a phenomenon called parameter turning (Janssen, 2002; Lansing, 2002; Waldrop, 1992).[10] A particular move of a unit could result in either benign or malign systemic effects, depending on how other actors respond and on the kind of cascading effects that it triggers. In other words, the properties of a system cannot be understood as the simple addition of individual contributions by the system's components. A complex system is dynamic in that the emergent features of the system require continual interactions among the system's components. A complex system is always in flux, yet the on-going interaction of the units generates dynamic patterns, from which systemic characters emerge (Johnson, 2001).

Saying that a complex system is one of order amid chaos does not mean that its aggregate patterns remain unchanged. On the contrary, the mechanisms that govern the interactions among individuals also evolve in response to the environment (Kauffman, 1995). Such a selection process allows the system as a whole to adapt to the changing context. In a SES, particularly, human creativity and the diversity of institutions and rules are able to generate a large number of alternative mechanisms in the process of trial and error.

An irrigation system is a complex system of which irrigation performance is the emergent quality constituted by numerous decisions and actions of actors of different capacities in disparate situations. A well-performed irrigation system is characterized not only by well-maintained infrastructure, but more importantly a productive working order of farmers (as resource users) and irrigation management staff (as infrastructure providers). Such a productive working order is an emergent pattern that is not the outcome of the command of a central pacemaker.

Water in a system flows from the head end to the tail end through a network of canals. The flow nature of water implies a high degree of interdependence among individuals involved in the processes of appropriation and management (Ostrom & Gardner, 1993; Lam, 1998). While the task of irrigation management involves much interdependence, decisions by individuals as to what to do and how to do in a particular situation are often highly independent. For instance, a farmer at the head end who tries to stop the water in a canal a little longer in order to divert a little more water to his fields would unlikely be able to comprehend how his seemingly trivial and innocent act might affect the operation of the system as a whole. From the perspective of the farmer, the interdependence is highly invisible and incomprehensible.

The challenge of coordination in such a complex and uncertain setting is substantial. It goes beyond the social dilemma portrayed by the Prisoners' Dilemma Game, which has often been by scholars to understand the collective action problem involved in common pool resource management (Ostrom, Gardner, & Walker, 1994). Instead of a matter of strategic calculation, the problem here is how to coordinate a large number of decisions in such a situation where the link between individual actions and aggregate outcome is highly complex and uncertain (Lansing, 1991). Also given the nonlinear dynamics and the possibility of parameter turning, some mechanisms have to be in place that identify and counteract cascading negative feedbacks, and facilitate positive feedbacks (Arthur, 1994). Finally, in a complex system, the adaptability of the system is an emergent pattern of the responses of individual to the changing environment. The mechanisms that are able to translate individual adaptations into systemic adaptation determine the resilience of the SES.

An Epistemic System

A major feature of a SES as a specific type of complex systems is its human and hence epistemic dimension. Unlike in many other complex systems where the autonomous units passively respond to others and the environment, a SES is activated by human beings who have the abilities to (1) think and foresee action-outcome links, (2) acquire and appreciate value and meaning of action, and (3) learn and conduct trial-and-error. The epistemic nature of the SES opens up opportunities for development and innovation, but at the same time generates a great deal of uncertainty and complexity. Understanding the design and operation of the SES requires that one pay serious attention to human cognition, and how it is reflected in the social, and even physical, infrastructure used by human beings in problem solving.

Human beings are boundedly rational. Fallible individuals in a complex system find themselves in a continuous process of making sense of the situation in which they find themselves, and develop strategies to make the best out of the situation. The architecture of human cognition, then, takes on an important role in understanding human choice and action (Jones, 2001, 2002, 2003; Simon, 1981, 1985). Individuals develop mental models to frame the world as they see it. The mental models help individuals make sense of the world by (1) stipulating the definition of the problem in hand, (2) constituting individual preferences (what should be wanted), (3) laying out causal action-outcome relationships, and hence possible alternative courses of action, (4) specifying criteria for the choice of the appropriate alternatives. Note that the perfectly rational model of man used by economists and rational choice theorists can be considered to be a particular type of model in which individuals have a rather clear idea about the problem situation. In other words, even rational choice is embedded in the prior and broader question of how the mental model is built at the first place. In a complex situation, rationality cannot be assumed but has to be explained (Jones, 2003).

Several characteristics of mental model building are noteworthy. First, mental models are rooted in genetic and cultural heritage of a community. Social scientists have found that human beings' abilities of empathy and of engaging in reciprocal interaction provide themselves with the potential for developing mental models for mutual betterment (Ostrom & Janssen, 2002). The viability and validity of a particular mental model depends on whether it is shared among, and understood by, individuals in a community. In other words, mental models are embedded in the broader cultural and social understanding of a community of individuals, who share common experiences and predispositions of action (North, 1990).

Second, once a mental model is adopted, it has the advantage of economizing cognitive capacity for individuals by identifying the essence of a problem situation and focusing individuals' attention. Yet a mental model is a two-edged sword. While it simplifies, it also confines individuals' vision. Problems arise when a mental model no longer captures the essence of a problem as the problem evolves. Mental models are sticky, and inevitably with biases built in. How to strike a balance between stability and change affects the viability of individuals' adaptive efforts (Denzau & North, 1994).

Third, human beings are endowed with the ability to imagine and to come up with new ways of looking at their circumstances. In particular, political scientists have argued convincingly that individuals facing social dilemmas, in which individuals' short-term interest is not consistent with collective aggregate interest, are able to design rules and working relationships to change the situation in which they find themselves (Ostrom, 1990, 1992). So mental models are constantly tested and challenged. When enough evidence about the inadequacy of a particular model is accumulated, the mental model currently in use could be replaced.

Fourth, mental models are constituted by a set of associations (between concepts and empirical referent, and between causes and consequences) accumulated as individuals learn through their experiences of problem solving and interaction (Arthur, 1991; V. Ostrom, 1997). It means that mental models are always embedded in experiences in particular contexts, and underlined by the learning process. Individuals possess a repertoire of potential metaphors and beliefs, which constitute the building blocks for mental models.

The specific features of human cognition have serious implications for the study of irrigation institutions in Taiwan. First, prior studies have shown that the success of Taiwan's irrigation management hinges upon a large array of diverse local institutions developed by farmers in disparate local communities to cope with irrigation problems that are location-specific and time-specific. As Denzau and North (1994) argue, institutions are simply mental models externalized. What are the mental models in the repertoire that have been drawn upon by the farmers in the coping with the macro disturbances? Are there commonalities across these models that explain their adaptive capacity? Second, the design of the mechanisms that help generate and maintain such a diverse repertoire of mental models is instrumental to the resilience of the system. What are these mechanisms and how do they work? Have the macro political economic disturbances impact on these mechanisms? Third, a mental model is effective only if it is shared and commonly understood by a community of individuals. What is it in the Taiwanese system that makes the shared learning possible? How does the shared learning process and capacity affect farmers' adaptation to the changing environment?

A Hierarchic System

Simon (1962) defines a hierarchic system as one "that is composed of interrelated subsystems, each of the latter being, in turn, hierarchic in structure until we reach some lowest level of elementary subsystem." In irrigation, for instance, a river system is often composed of several smaller river valley systems, and each of the river valley systems is in turn decomposed into branches, laterals, and sub-laterals. Each of the smaller systems at a particular level is to a certain extent self-contained, yet is somehow related to a larger system.

A hierarchic system usually comprises of sub-systems that operate coherently, yet are nested within one another. Different tasks involved in a system might be of various scales in terms of scope and time (Ostrom & Janssen, 2002). The difference in scales could be both horizontal, in that activities of scales overlapped with one another at different levels, and vertical, in that some activities in a system constitute self-contained subsystems. Such polycentric feature is particularly conspicuous in irrigation management that involves multiple tasks of various scales. Farmers sharing waters from a branch canal develop an order of water distribution and appropriation. Such a local irrigation order is in turn sustained by the larger concerns of managing the main canal and coordinating the distribution of water among branches. The management of the physical infrastructure in turn is conditioned by the concerns of how irrigation management relates to the broader issues of water resource management and economic development; and these issues are often managed in the context of national governance.

Several features of the multi-scale character of a hierarchic system are particularly important. First, structures and processes of different scales on different levels tend to have very different spatial and temporal attributes.

Irrigation systems at the tail end of a large channel could be operated on a cycle very different from those at the head end, and even more different from the operation pattern of the larger channel. Also the fields at the tail end near coastal areas are more sensitive to the problem of salinity than the fields at the head end. The operation of the SES involves institutional arrangements of multiple scales, each with different design imperatives. Second, structures and processes at different levels tend to affect one another. Usually the slower, larger levels constrain the behavior of faster and lower levels (Gunderson & Pritchard, 2002). The operation of the channel that delivers water from a reservoir to laterals is likely to affect the operation of the systems that receive water from the laterals. Also the resilience of one level does not necessarily enhance the resilience of another level. Systems that keep absorbing shocks at the local level tend to numb the vigilance of the larger system; when the physical structure of the larger system gets to a point of no return, the damage could be disastrous. The synchronization of processes at different levels is of major importance.

In the institutional domain, the hierarchic nature is manifested in organizations, or regimes, that operate at several levels. The regimes at multiple levels deal with problems of different sizes and scales, and have jurisdictions over a multitude of policy communities. Two dimensions of the multiplicity are noteworthy. First, while the boundaries or jurisdictions of various regimes are usually somehow correspondent to the scales of various biophysical processes and structures, they are not necessarily so. In irrigation in many South Asian countries, for example, a unifying bureaucracy is in place to manage all the irrigation matters from the management of water source all the way to water delivery to farmers' fields. Obviously the assumption is that the large-scale bureaucracy is able to cope with the diversity embedded in various domains of collective action involved in irrigation management. Research in irrigation, however, shows that the systems in which multiple regimes at different levels are in place to cope with problems of different scales are likely to be more efficient than those managed by a unifying regime, or those systems in which regimes and processes are not matched appropriately (Ostrom 1992; Lam 1998).

Second, although regimes at different levels are hierarchic and somehow related to one another, they are not necessarily closely-linked. The issue involved here is the dilemma between coordination and autonomy. On the one hand, a hierarchic system could be decomposed into processes and structures that are self-contained enough for easy problem solving; regimes should be put in place at different levels to address these structures and processes. On the other hand, while decomposable, the structure and processes are necessarily related to one another, frequently in a non-linear manner; that, in fact, is what makes these structures and processes one system. Coordination then becomes essential. Being able to strike the balance between autonomy and coordination affects the viability of the system. In irrigation, for example, O&M is best left to farmers' organizations at the sub-lateral level, where time-specific and place-specific local information is readily available. Yet these local organizations would need to coordinate with one another when water in the main channel has become scarce. Under those situations, the preferences of the local organizations might not be consistent with one another. The dilemma between autonomy and coordination underlies the problem of nesting of regimes at multiple levels.

A Dynamic Problem-Solving System

Disturbance can be understood as a series of events that could possible disrupts the structure and processes of a SES (Janssen, Anderies, & Ostrom, 2003). Understanding the nature of the disturbance regime is important not only because they could pose as challenges to the SES; but more importantly they are part of the SES. A SES, like any other complex system, is not a static mix of variables, but a dynamic system composed of a complex set of on-going relationships among human actors and between human actors and the biophysical world. An irrigation system is not recognizable by its infrastructure or members, but the ways members interact with one another in an effort to utilize the infrastructure to attain some human purposes. Disturbances provide the driving force for the operation of the structures and processes of a SES. As Waldrop (1992) puts it, “a complex system is always in the process of attaining stability amid chaos”.

Nature could impose not only risk but also uncertainty (unknown) (Simon, 1981) and ambiguity (different interpretations) (Axelrod, 2003). A disturbance regime could be described by various attributes, such as severity and frequency. Disturbance could be originated from within the SES or without from the environment (Janssen, Anderies, & Ostrom, 2003). Yet all disturbances manifest their effects through impinging upon the elements, and the relationships between the elements, in a system. Conceptualizing disturbance as an inherent component of a SES, two dimensions are of particular importance to understanding the resilience of the SES. The first is the degree of predictability. Predictability is concerned with the problem of risk. A cyclical phenomenon, such as drought cycles, is more predictable and could be taken into account in advance. A more haphazard phenomenon, such as a landslide is more unpredictable and could let people off guarded. So individuals have a better understanding of the probability of predictable events than that of unpredictable events. Yet regardless the degree of predictability, both types of disturbances are foreseeable. People know that they are forthcoming, but just don’t know when and where.

There is yet another type of disturbances that defy ex ante prediction. These disturbances are unforeseeable, in that people have only very rough ideas about the existence of these disturbances, or the form they take (Axelrod, 2003). Facing these unforeseeable disturbances, uncertainty prevents individuals from estimating the probability function of these disturbances. In irrigation management, the impact of economic development belongs to the type of unforeseeable disturbances. While both farmers and irrigation officials know that economic development is going to affect how irrigation is managed, exactly how the impact is going to be like is unclear. Uncertainty is particularly serious when disturbances take the form of diffused creeping changes. Farmers might be aware that their neighbors are increasingly less concerned about the conditions of the canals and less willing to cooperate. Yet they cannot tell exactly why and how that happened, and when it began. Disturbance from politics is another example of unforeseeable disturbance. While everybody knows that politics affects irrigation management, exactly what form politics takes in particular circumstances cannot be easily foreseen. It would be difficult for individuals, or the system, to develop strategies ex ante to cope with political disturbances.

Coping with Complexity: Institutional Design, Resilience, and Adaptation in Taiwanese Irrigation

To attain a productive working order in irrigation requires that the dynamics embedded in the complex system be harnessed effectively (Axelrod & Cohen, 2000). The design of Taiwanese irrigation institutions has, to a large extent, allowed the irrigation systems to cope with such dynamics. External disturbances create perturbations, which might in turn impact on the operation of the system. In the process of adapting to the perturbations, the institutions themselves are subject to challenges, and hence evolve. The viability of the adaptation and evolution affects the resilience of the system. With reference to the dynamics of the SES identified, I shall in the following examine how the Taiwanese irrigation systems deal with the tasks of coordination, repertoire building, and nesting.

Coordination

A major feature of Taiwan's irrigation institutions is that they provide arenas and logistic support for problem solving by farmers at the field level.[11] Farmers are organized into self-organized Irrigation Groups (IGs), which are responsible for irrigation operation and maintenance (O&M) in the field. Farmers in an IG elect an IG leader, who is given the mandate to coordinate and liaise with the IG members concerning O&M activities. In some IGs, water guards are hired to help on water allocation and minor maintenance works. A major feature of the IGs is that they are organized on the basis of hydraulic boundaries. In Taoyuan areas where a large number of ponds were in place for water storage, for example, the IGs there are organized in accordance with the areas irrigated by individual ponds. In areas irrigated by water from reservoirs such as the Chianan areas, an IG usually includes irrigators served by the same sub-lateral. By matching the boundaries of the IGs with hydraulic areas, the task of irrigation management is effectively compartmentalized into subtasks; more importantly, farmers in each IG are in effect assigned to coordinate among themselves with reference to the management of the subtask. That farmers at the local level are allowed to work out solutions to cope with the "localized" irrigation problems enables better utilization of local information. The IG arrangements, by nature of its proximity to local community, can effectively draw upon social capital that has already been developed in local community to attain coordination in the O&M processes (Lam, 1996a).

Coordination at the sub-lateral level with the IG as the basic problem-solving unit by itself is inadequate. While the IG arrangement enhances clustering among farmers in particular hydraulic areas, how disparate IGs can connect with one another affects the overall performance of the system as a whole. Closely knitted communities provide solid foundation for collective problem solving, by themselves alone they are fragile in dealing with external shocks or changes of a large-scale, and their activities might not be consistent with one another in pursuing larger-scale collective actions (Buchanan 2002; Watts, 2003). Research on the so-called small world phenomena provides very good insights for understanding the institutional design reconciling clustering and connect-ness. A major finding of the research is that allowing a small number of random links developed between individuals can provide the glue that drastically shortens the social distance between individuals belonging to different communities. These random links do not have to be strong; the mere existence of these links serves a miraculous function of linking up closely-knitted communities. In irrigation management, cross-community coordination is of utmost importance to irrigation efficiency.

In Taiwan, two institutional arrangements are in place to connect the clustered groups (the IGs). The first is the irrigation plans worked out by Irrigation Associations (IAs) every year as the blueprint for water delivery. The plans are made mainly based upon the geological and topographical conditions of farmers' fields and expected cropping patterns, with minor adjustments made every year to take into account the changes in the size of irrigated areas and possible changes in land use. While the plans are so meticulous that even the exact amount of water allocated to a particular patch is specified, they are frequently not strictly followed in actual water distribution. In fact in systems where the major source of water is rivers and creeks, irrigation plans are made but seldom used. Yet these irrigation plans do serve a very important coordination function. The amounts of water to particular field as specified in these plans are considered farmers' entitlement of water. They serve as the yardstick around which adjustments be made. So disparate IGs have a rough idea about the overall picture of how water should be distributed, which could impose the bounds within which the IGs can make mutual adjustments. In a way these plans provide a mental map for farmers to engage in mutual adjustments.

Second, random links are put in place that provide bridges linking up the IGs and the working stations. The working stations hold regular IG leaders meetings twice a year, usually scheduled for the time right before irrigation starts. Other than these regular meetings, ad hoc meetings will be held to cope with emergencies. Whether these meetings can provide an effective arena for decision making and deliberation has been subject to question. Anyone who has observed these meetings would note that they are more like social gatherings and largely dominated by IA officials. Very often the attendance rate is low. Despite that, these meetings serve the important function of weak ties linking up the IGs. As suggested by the literature of network, the ties linking up clustered groups do not have to be very strong. The major function of these weak ties is to (1) shorten the social distance between clustered groups so as to enhance coordination and (2) provide access to learning from one another (Watts, 1999, 2003). A farmer put it succinctly, "People attend these meetings just to know what is going on with one another; if I encounter problems of importance, I would definitely contact the workings station chief direct. These meetings are not supposed to be an arena for problem solving." Other than meetings, IG leaders are engaged in activities of various kinds organized by the IAs. For example, every year an irrigation festival is organized at which some "model IG leaders" will be given awards; also an IG leader is entitled to an "overseas field trip" during his term of service to broaden his horizons. All these seemingly trivial and irrelevant activities help sustain the connect-ness among the IG leaders.

Random links are also built in by rotating working station staffs every now and then. A major characteristic of the IAs is that, through a network of working stations, the IA staffs are stationed in the field for a relatively long period of time so that they are made embedded in the communities they serve (Lam, 1996a). Again, embeddedness enhances clustered-ness, yet linking up clustered groups requires that random links be put in place to shorten social distance. Working station staff are posted to different working stations in their careers. Yet unlike in South Asian countries where irrigation officials are often posted to particular positions for a short period of time, IA staff usually spend a prolonged period of time in a station. The prolonged stay, however, is not like that in Japan where the small size of Farmland Improvement Associations has basically locked in irrigation staff to a particular locale for their careers. The IA staff usually have a number of postings during their careers. The infrequent yet regular movement of staff helps creating links between officials and farmers across communities.

The "official version" of Taiwanese irrigation management that every detail in water delivery is under control is, at best, misleading. Coordination in actual water delivery in Taiwan is maintained not by a grand plan or a pacemaker, but by an array of institutional arrangements that encourage local problem solving on one hand, and local mutual adjustments on the other. While such a mode of coordination seems not forceful, and certainly does not fit neatly with the engineering image of orderly water allocation, it is tremendously flexible and robust. It allows farmers in disparate situations to decide on how much effort they want to put in irrigation management, and their best ways to do it.

The situation in Chianan provides a good illustrating case. In Chianan areas, irrigation water mainly comes from large reservoirs; rotational irrigation is practiced. The changing economic setting has triggered the development of a large array of institutions to cope with the impact of macro economic changes in disparate locations. Farmers in different locations along the canal would assess the profitability of farming (based upon their knowledge on the cropping patterns of their fields and the market situation), and work out very different water allocation practices that require different levels of involvements and input on their part. In areas where two crops a year is possible, an irrigation slip system, in which farmers will get the amount of water specified by irrigation slips distributed by the working stations, is adopted. Under the irrigation slip system, farmers need to get to the field to see to it water is actually delivered, and the irrigation plan is strictly complied. In areas where a three years two crops pattern is adopted (where farmers are allowed to grow the second crop twice in three years), a responsibility system is developed in which the water guards hired by the IAs have full discretion in water allocation. Under the responsibility system, farmers' input is minimal. Interestingly at the tail end areas closed to the seashore where salinity problem is serious and productivity is low, the irrigation slip system is adopted. The general pattern is that farmers' input and agricultural productivity (or profitability of farming) are in a U-shape relationship. Farmers' input is high when farming is profitable, and the input decreases with the decrease of profitability; yet at the worst scenario where the survival of the fields is at stake, farmers are willing to do more.

Local institutions have been adjusted to reflect and cope with such a dynamic. The flexibility of the institutions can cope with the low incentive mode of agriculture on one hand, and retain a certain level of vibrancy in irrigation management on the other.

The viability of the flexible institutional arrangements in Taiwan depends on the willingness of a small group of IG leaders who serve as the bridges connecting up farmers. The IAs are surely aware of the situation, and have adopted measures to beef up the support and incentives for the IG leaders. In Taoyuan IA, for example, IG leaders are allowed to operate aquaculture in the ponds that store irrigation water for the IGs. In Chianan, the IA provides an operational budget for each IG. Other than material incentives, the connective-ness of the IG leaders is also strengthened. For instance, in some areas, the IG leaders are organized into associations. In Taoyuan, each managerial staff is required to visit the working stations at least twice a year. Although many IGs are no longer as active as before, the role of the IG leaders has become increasingly important for the purpose of coordination.

Repertoire Building and Learning

As discussed above, boundedly rational individuals make sense of the world by resorting to shared mental models that provide the assumptions and theories explaining the world. The fallible individuals, however, would not know for sure ex ante which mental models are appropriate for particular situations. A robust SES should allow for the generation and maintenance of a variety of mental models that could possibly be drawn upon for various problem situations.

A robust SES should possess two types of coping capacities in dealing with disturbance (Gunderson & Holling, 2002). For foreseeable disturbance, a repertoire should be developed so that an appropriate coping strategy is matched with the disturbance at the right time. In terms of institutional design, a major concern is that the strategies in the repertoire should be comprehensive enough to provide readily available action plans for possible scenarios on one hand, and should not be too exclusive to preclude the possibilities of taking into unique and new scenarios into account on the other. Another design concern is to improve the predictability of disturbances by utilizing local information and strengthening the information process capacity of the system. Coping with unforeseeable disturbances is more challenging. Given that little information is available, the institutional design concern is not about strengthening the contents of the repertoire per se, but improving the process of search for viable models and alternatives.

A major characteristic of Taiwanese irrigation is that it is a knowledge-rich system. As mentioned above, farmers in disparate locations are allowed to develop appropriate local institutions to cope with their local problems. Other than the autonomy to develop local institutions, an even more important feature is that the knowledge generated is systematically recorded. When I visited the Kung Wen working station in Chianan where the physical condition is hostile and the problem of salinity is serious, I was shown a pile of irrigation plans worked out by the local staff of the working station that have been used to “supplement” the formal irrigation plan promulgated by the Chianan IA. The IA headquarters staff of course were quick to discard these locally-made plans as rudimentary; yet it is the local knowledge embodied in these meticulous locally-made plans and the like that has enabled Taiwanese farmers and the irrigation systems to cope with diverse problems. Meticulously recording knowledge is not confined to local levels, but is regularly done at different jurisdiction levels of the irrigation sector. Anyone who visits the IAs will likely be shown the detailed handbooks that document management measures and practices for various contingencies. In fact, even the irrigation authorities in the central government have been doing likewise, compiling handbooks on very aspect of irrigation management.

These handbooks of course do not necessarily provide the solution to every problem; yet the knowledge recorded does constitute a repertoire of ideas that provides the building blocks for working out mental models. The practice of water stoppage during droughts is a case in point. The basic idea, as recorded in the handbook, is that prolonging the irrigation cycle by a few days could reduce water use without doing harm to the crops. Yet exactly how long the water should be stopped, how water stoppage can fit in irrigation rotation, and how water stoppage should be managed would all depend on the physical as well as institutional setting of particular systems. During my fieldwork, I found a variety of water stoppage rules used in different IGs. More interestingly, perhaps due to the close networks of the IGs, there is a high degree of cross-community learning. Farmers in an IG often draw upon the experiences of their counterparts in other IGs in developing strategies and techniques to deal with different contingencies. It is noteworthy that the cross-community learning is not confined to irrigation matters, but pertains to farming matters in general.[12]

Mental models are not only concerned about the physical and operational dimensions of irrigation management; broader issues such as the orientation of the irrigation sector in general are also of major importance. Unlike the typical irrigation agency in many other Asian countries, the Irrigation Associations in Taiwan are not merely engineering agencies. As discussed above and elsewhere (Lam, 1996a), the IAs are parastatal organizations owned by farmers, staffed by professional engineers and managers, controlled by local politicians, and supported and supervised by the government. In other words, due to their parastatal and association nature, the IAs include in their staffs a combination of engineers, managers, professional administrators and local politicians. So unlike a typical irrigation agency, the IAs have the capacity to address irrigation management not only from the engineering perspective, but also from the social and policy perspectives. Such capacity is particularly important in the context where not only the IAs but the whole irrigation sector has to find a niche to re-orient itself. More importantly, incentives are built in so that various actors, particularly the politicians who control the IAs and the IA staffs, are eager to play the role of the policy entrepreneur. So when the water rights of the IAs were challenged by the industrial and domestic sectors, the IAs were quick to put the issue in the broader historical-social perspective, emphasizing that although rainfall may come from the sky, water in the canal is available only because generations of irrigation staff and farmers have put in tremendous management efforts. When the IAs were asked to generate revenues to finance some of their activities, they could easily come up with innovative ideas such as partnering up with the power companies to piggyback on water flow for power generation.

With the decline of agriculture and the increasing politicization of irrigation management, learning has become more confusing. Sometimes farmers could get stuck in a model that may provide short-term benefits but cause long-term damage to their systems. Perhaps the best example is the controversy concerning membership fees (Lam, 2004). When irrigation is portrayed as merely one type of public services that the government should provide for free, farmers and irrigation staffs are getting more and more dependent; and tend to dwell on strategies that seek rent from the government. Even the farmers agree that having the government to pay the membership fees on their behalf has changed their relationship with the IAs; yet the dependence model has become seemingly so self-evident that nobody is willing to challenge it.

Nesting

To cope with the multi-scale nature of irrigation management, irrigation institutions serving activities of different scales at different levels are nested within one another. As mentioned, the IGs are organized around hydraulic (at sub-lateral level) and community boundaries; above the IGs are working stations that are organized to cover a number of IGs, in accordance with larger hydraulic boundaries (at lateral level). In some larger IAs, a number of management stations are in place to take care of a number of working stations in a still larger hydraulic region. The IA headquarters oversee the overall irrigation management in particular regions. While each unit is given the task and much autonomy in managing irrigation in a particular area, it is at the same time supported and covered by a higher-level unit that manages a task of a larger scale. Institutions at different levels are nested within one another. Unlike the typical irrigation bureaucracy that also emphasizes layers of units, the IGs and working stations in Taiwan enjoy high degrees of autonomy and discretion (Lam, 1996a; Moore, 1989).

The nesting arrangements enhance complementarity and embeddedness (Lam, 1996a; Evans 1996). By complementarity, I refer to the mutually beneficial division of labor among actors in different positions. Tasks of different scales require quite different expertise and resources to deal with. For example, while the IGs might be able to help fix small leaks on canals, larger scale emergency maintenance works need to be dealt with by the working stations or even the headquarters. By the same token, while the IGs might command good local information about the canals at the sub-lateral level, information about the water flow in the main channel will need to be collected by management stations.

In terms of coping with coping with disturbances, complementarity serves the important function of keeping the system flexibly decomposable. Units could be easily re-grouped into units of different scales to cope with problems of different scopes. Managing water allocation in droughts is a good case in point. Depending on the scale and seriousness of the drought, rotation of different types involving working units of different scales could be adopted. When water shortage is mild and considered temporary and short-term, rotation in the form of farmers within an irrigation block taking turns to receive water would suffice. More serious water shortage might require that irrigation blocks take turns to receive water. When droughts happen, rotation might be done on the basis of areas irrigated by laterals. If the drought persists, rotation would be done on the basis of river systems.

Complementarity also serves as the function of the safety valve that makes the system more resistant to external shocks. The simplest form of safety valve is putting a certain degree of redundancy in place (Costanza, et.

al., 2001). For example, instead of relying on the IG leaders to patrol the canals, the working staff will also do the patrolling. Another form of safety valve is substitution. As discussed elsewhere (Lam, 2004), one major strategy of the IAs to cope with the decreased incentive and input of farmers in irrigation management is to construct and maintain the infrastructure as well as possible so as to reduce the demand for farmer's input. Safety valve can also takes the form of the provision of buffer by larger units to smaller units, so that the smaller units can operate in a more stable setting. Perhaps the most illustrative example of buffer is the option of fallowing provided by the government. The government and the IAs would make assessment of water availability before the planting season begins. If water is judged to be scarce or droughts are expected, farmers can fallow their lands for the season with compensations from the government. By absorbing part of risks of farmers, the option of fallowing in effect puts on bounds on the demand for irrigation management for the systems, and avoids extreme situations.

Another example of buffer is concerned with the debate on water rights. In close cooperation of the agriculture and irrigation agencies in the central government, the IAs have been successful in defending the water rights assigned to irrigation. Simple mathematics shows that fallowing, shrinking irrigated areas, and changing cropping patterns have all reduced the demand for irrigation water. In practice, however, shrinking irrigated areas and more diversified cropping patterns could mean more scattered fields and more complicated irrigation schedules, and hence higher demand for irrigation water. By insisting on retaining the water rights, the IAs in fact provide adequate cushion in terms of water availability for farmers and local irrigation staff to cope with the changing environment.

Embeddedness refers to the intertwining of processes and institutions that helps create added value for the processes. Embeddedness can enhance the operation and function of the processes. For example, the IG leaders are the ones who enforce the order of water distribution at the field level. Usually the IG leaders are able to get farmers' compliance through persuasion and reconciliation. Yet there are situations in which water is very scarce or serious feuds between farmers exist; the moral authority wielded by the IG leaders alone might not suffice for these situations. The standard practice is that the staff from the working stations or even the IA headquarters will "accompany" the IG leaders to patrol the canals. The presence of the IA staff surely enhances the legitimate authority of the IG leaders in discharging their duties. Another example of embeddedness is the monitoring of IA staff. Through daily interaction, the farmers can effectively serve as the third-party monitor to supervise the IA staff at the working stations (Lam, 1996a; Moore, 1989).

Sometimes embeddedness operates in the form of units at a higher level controlling possible excesses by units at a lower level. In Pingtung areas, the major source of water is groundwater. Water delivery in the areas mainly involves the Pingtung IA providing electric pumps for farmers. Water appropriation is highly individualistic; whenever the farmers need irrigation water, they can simply turn on the pumps to get whatever amount of water they want. Given the large number of pumps, the individualistic nature of water appropriation, and the seeming abundance of groundwater, neither the farmers nor the IA have strong incentives to prevent water wastage. It is commonplace that farmers just leave the pumps turned on, and let the water flow. While the farmers and the IA do not care about water wastage, their over-appropriation of groundwater has already cause land subsidence in the coastal areas of Pingtung. Instead of intervening direct, the central government has imposed a quota on the budget that can be spent on electricity for the pumps. The quota in effect puts pressure on the IA to economize the use of pumps and hence the groundwater. The outcome has been that the IA has installed meters to closely monitor the operation of the pumps, and worked out stricter plans.

Embeddedness in terms of controlling excess has played a very important role in the relationship between the central government and the IAs. As mentioned above, a major challenge facing Taiwan's irrigation institutions has been the changing nature of the IAs. As farmers face little incentive to get involved in irrigation management and are getting increasingly detached, the IAs are becoming farmers' organizations without farmers' involvement. A consequence is that the IA staff and the politicians who control the IAs become the de facto owners of the associations. Such a change threatens the viability of the IAs, whose logic of design is based upon the assumption of farmer ownership.

To maintain the operation of the IAs, the government plays an important role. By a series of policy measures that set the bound for the operation of the IAs, the government has effectively minimized the extent of possible rent-seeking activities. These measures have been mainly focused on two areas. The first is the imposition of financial prudence. The IAs are not allowed to spend the money they have earned from property sales on activities other than irrigation. Also the amount of subsidies to the IAs is tightly controlled. In the words of a senior government official whom I interviewed, "as long as the IA staff do not command too much financial resource, they cannot do too much harm." The second is to work out better laws and regulations for the operation of the IAs. Instead of relying solely on administrative control as before,[13] the government has been trying to codify rules and laws that could provide a better legal framework for the operation of the IAs.

Complementarity and embeddedness have enabled Taiwan's irrigation systems to adapt and adjust to the changing environment. Of course, both complementarity and embeddedness have their limits. When infrastructure is considered to be able to replace farmers' effort, and when IA staff are thought to be able to replace the IG leaders, the vibrancy of the system could easily be undermined (Lam, 1996b, 2001, 2004). What is more unfortunate is that individuals might not be even aware of the loss. When the deterioration reaches the threshold, cascading effect in terms of rapid deterioration could happen. Particularly, embeddedness would work only if the IAs remain vibrant and autonomous entities. When they are so embedded with the government that they lose their autonomy and self-organizing capacity, they could become de facto subordinate organizations of the government.

Conclusion

Despite the challenges posed by the change in the macro political economic environment, Taiwan's irrigation systems have shown a high degree of resilience to external shocks. Although irrigation seems to be fading to the background, the irrigation institutions have succeeded in finding new niches and developing new capacity to thrive. The general pattern is that while the sector as a whole has been in flux and gone through many changes, the vibrancy of the system remains.

The major finding is that the design of Taiwan's irrigation institutions has been able to cope with the dynamics inherent in the SES. It allows various actors and organizations at different levels to engage in continuous learning and adaptation. Having said that, however, resilience does have its limit. The viability of Taiwan's irrigation management ultimately hinges upon a certain degree of involvement and commitment of farmers. While institutional design can help reduce the level of demand for farmers' commitment and self-organizing effort, it is no perfect substitute. When farmers totally retreat from the tripartite endeavor, and irrigation management becomes no more than the battle of sexes between the government and IA officials, the collapse of the system can be expected.

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Endnotes

[1] As of 2001, more than 37% of the heads of farm households in Taiwan were over 65 of age (COA, 2003).

[2] As of 2001, there were about 726,000 farm households in Taiwan, which was about 10% of the total number of households in the country. Such a percentage had remained quite steady. It is interesting to note that the number of total number of "full-time" farm households, who derive their major income from farming, has been on the rise in the last ten years. In 1992, there were about 100,000 full-time farm households in Taiwan; by 2001, the number had increased to more than 140,000 (COA, 2003).

[3] A majority of farmers are unwilling to sell their lands. When the old farmers pass away, instead of selling their lands, their sons will inherit and divide the lands among themselves. As a result, the number of farming households has increased.

[4] As of 2000, the annual precipitation of Taiwan was 90.5 billion cubic meters; about 19.5 billion cubic meters of water was available for use. About 15.4 billion cubic meters was used for agriculture.

[5] This study adopts the definition of resilience developed by Gunderson and his colleagues. Resilience is measured by the magnitude of disturbance that can be absorbed before the system is restructured with different controlling variables and processes.

[6] During the period from 1993 to 1997, government subsidy on average accounted for almost 70% of the total expenditures of the IAs. For detailed figures and analysis, see AERC (1999).

[7] Irrigation Associations in Taiwan have long played an important role in political mobilization. At the times when Taiwan was under the authoritarian rule of the Nationalist Party (the Kuomintang (KMT)), the IAs, together with other semi-governmental organizations such as the Farmers' Associations, were used by the government to allocate resources and hence political powers to local politicians in exchange for their political loyalty. Given that these organizations control major agricultural resources and are tightly controlled by the KMT, they have been effective political mobilization mechanism for elections. Even nowadays the KMT is no longer the ruling party and the IAs do not have as tight control over farmers' voting as before, the IAs are still mainly controlled by the KMT. Of the 17 IA chairmen, 16 of them are KMT members. The Chairman of the Joint IA is a member of the Central Committee of the KMT.

[8] As of 2001, more than 92% of Taiwan's farm households had a landholding size of less than 1 hectare.

[9] As of 2001, the average annual income for farmers per capita was about NT224,000 (around US$6,600 in 2001), which was around 70% of the average annual per capita income for non-farm households.

[10] Camazine et. Al. (2001) defines parameter turning as the occurrence of bifurcation—a sudden transition from one pattern to another following a small change in a parameter of the system.

[11] For detailed discussions of Taiwan's irrigation institutions, see Lam (1996a, 2001, 2004) and Moore (1989).

[12] I was particularly impressed by the development and sharing of farming techniques by farmers that give better and more paddy yields while using less water.

[13] In the past, the interaction between the IAs and the central government was mainly through administrative orders by the government. A consequence was that while the IAs tended to rely on the government for decisions; the government found itself not having sufficient resources to exercise effective control and created administrative bottlenecks. Interestingly, the lack of laws and regulations allowed room for political bargaining and manipulation, which often resulted in inconsistency.