Diagnose Complexity in Social-Ecological System: Understanding Irrigation Institutional Changes in Imperial China [1]

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Abstract

Adopting the diagnostic approach that Ostrom (2007) proposed, this paper offers an in-depth explanation of the emergence of irrigation self-organization in Qing China. The paper examine the underlying variables identified by Ostrom (2009) for self-organization with Chinese empirical materials from a history dynamic perspective, and shows that the SES framework is fairly robust as a powerful tool to diagnose the complexity in the social-ecological system. Besides the variables affecting the likelihood of self-organization identified by Ostrom (2009), the variables in contextual settings have been proved to be important such as the population trends, government policies and globalization, which provided initial forces or supporting environment for the development of self-organization in this study. Identifying the complex interactions among the variables is a big task for social scientists and better theories can be developed with the guidance of the SES framework.

Key Words: Social–Ecological System (SES), Diagnostic Complexity, Irrigation Systems, Self-Organization, China

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1. EXPLAINING USERS' SELF-ORGANIZING TO MANAGE IRRIGATION SYSTEMS

The governing of common-pool resources (CPRs), such as forests, fisheries, and irrigation systems, contains complexity in which the social systems interact with natural systems. In a long period, a prevalent viewpoint was that the users of CPRs, could not self-organize to manage the resource. Many scholars often recommended the imposition of either of state or market governance based on the theories of Gordon (1954), Demsetz (1967) and Hardin (1968). In the 1980s, scholars began to recognize the need for further research on how diversely structured systems for governing CPRs performed in the field (NRC, 1986).

In *Governing the Commons*, Elinor Ostrom (1990) shows that there are many different methods of CPR governance, in particular self-organization and self-governance by the users of the CPRs. From then on, more and more studies in multiple disciplines have found that some resource users have invested their time and energy to achieve sustainability.

Following these studies, a question remains: How to understand the users' self-organizing activities? Why do some communities succeed in self-organizing to manage the local resources, while some others have failed? Ostrom (1990) posited a set of eight design principles that characterize long-enduring, self-governed CPRs institutions. These principles have been approved to be well supported empirically, and furthermore a probabilistic, rather than a deterministic, interpretation of the design principles is warranted (Cox, Arnold and Tomas, 2009).

However, it is a challenge to diagnose the problems and potentialities of complex social–ecological systems (SESs). Many variables affect the patterns of interactions and outcomes observed in empirical studies. After undertaking a careful analysis of the research examining the factors likely to affect self-organization and robustness of common-property regimes, Agrawal (2001) identified more than 30 variables that had been posited to affect the likelihood of self-organization and collective action in CPR settings. Ostrom (2007) developed a diagnostic method to organize various variables in a nested, multitier framework, which is shown in Figure 1.

This SES framework enables scholars to organize analyses of how attributes of a resource system, the resource units generated by that system, the users of that system, and the governance system jointly affect and are indirectly affected by interactions and resulting outcomes achieved at a particular time and place. Using such a framework also enables one to organize how these attributes may affect and be affected by the larger socioeconomic, political, and ecological settings in which they are embedded, as well as smaller ones. Each of the eight broad variables shown in Figure 1 can be unpacked and further unpacked into multiple conceptual tiers (Ostrom, 2007).

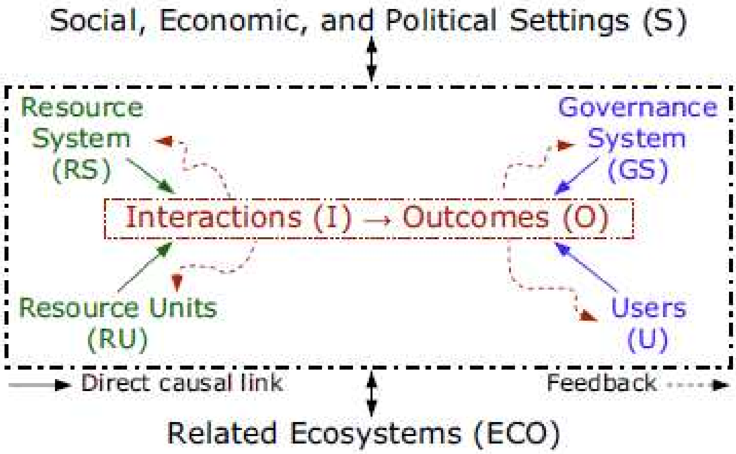

Figure 1 A multitier framework for analyzing an SES
Source: Osrom (2007).

Based on field research, Ostom (2009) used this framework to identify 10 subsystem variables that tend to affect the likelihood of self-organization in efforts to manage a resource, which include size of resource system, productivity of system, predictability of system dynamics, resource unit mobility, number of users, leadership, social capital, knowledge, importance of resource to users, and collective-choice rules. Poteete, Janssen and Ostrom (2010) provide an update version with 12 most frequent variables identified in empirical studies as affecting whether user will self-organize. Also within this framework, a further review of the irrigation management literature highlighted some important factors to affect farmer participation, including water scarcity, size of WUAs, socioeconomic heterogeneity of users, leadership, social capital, distance to market, and government policies (Meinzen-Dick, 2007).

This paper will use the diagnostic approach within the SES framework, to explain why the self-organization pattern of irrigation management emerged in the Qing dynasty, but not earlier dynasties in Chinese history. About this question, a methodological foundation can be found in Poteete, Janssen and Ostrom (2010), which is the method to diagnose institutional change:

In analyzing empirical cases, the researcher or policy analyst must try to diagnose how the above factors affect the expected potential benefits and costs that users in a particular setting face if they continue old rules or attempt to change them. One would start with the listed variables and ask how they are likely to affect the benefits and costs of users. In particular cases, other variables may enter the diagnostic analysis. (Poteete, Janssen and Ostrom, 2010, p. 327)

Therefore, I will examine the underlying variables indentified for self-organization in prior literature with Chinese empirical materials from a history dynamic perspective, which will help us to explore the key factors and mechanism to explain the institutional evolutions of irrigation management. The list of second-tier variables used in this study is shown in Table 1.

TABLE 1 Second-tier variables in SES framework

<table>
<tr><th colspan="2">Social, Economic and Political Settings(S)</th></tr>
<tr><td colspan="2">S1-Economic development. S2-Demographic trends. S3-Political stability.S4-Government policies. S5-Market incentives. S6: - Technology. S7- Globalization</td></tr>
<tr><th>Resource System(RS)</th><th>Governance System(GS)</th></tr>
<tr><td>RS1- Water
RS2-Clarity of system boundaries
RS3-Size of irrigation system*
RS4-Water infrastructure
RS5-Scarcity*
RS6-Equilibrium properties
RS7-Predictability of supply*
RS8-Storage characteristics
RS9-Location</td><td>GS1-Government organizations
GS2-Non-government organizations
GS3-Network structure
GS4-Property-rights systems
GS5-Operational rules
GS6-Collective-choice rules
GS6a-Local collective-choice autonomy*
GS7-Constitutional rules
GS8-Monitoring&sanctioning processes</td></tr>
<tr><th>Resource Units(RU)</th><th>Users(U)</th></tr>
<tr><td>RU1-Resource unit mobility*
RU2-Water availability, by season
RU3-Interaction among irrigation units
RU4-Economic value of output
RU7-spatial&temporal distribution</td><td>U1-Number of users*
U2-Socioeconomic attributes of users*
U3-History of use
U4-Location
U5-Leadership*
U6-Norms/social capital*
U7-Knowledge of irrigation*
U8-Dependence on irrigation*
U9-Technology used</td></tr>
<tr><th colspan="2">Interactions(I)→Outcomes(O)</th></tr>
<tr><td>I1-Water use by diverse users
I2-Information sharing among users
I3-Deliberation processes
I4-Conflicts among users
I5-Investment activities
I6-Lobbying activities
I7-Self organizing activities
I8-Networking activities</td><td>O1-Social performance measures
O2-Ecological performance measures
O3-Extemalities to other SESs</td></tr>
<tr><th colspan="2">Related Ecosystems(ECO)</th></tr>
<tr><td colspan="2">ECO1-Climate patterns,ECO2-Pollution patterns,ECO3-Flows into and out of focal SES</td></tr>
</table>

Source: Adapted from E.Ostrom (2007), Meinzen-Dick (2007), Poteete, Janssen and Ostrom (2010).

2. THE EVOLUTION OF IRRIGATION GOVERNANCE IN CHINESE HISTORY

Irrigation for agriculture production is extremely important in China. With a long history of more than two thousand years of irrigation management, these irrigation institutions have evolved over time (Wang, 2005). During the early dynasties of Qin and Han (from 221 B.C. to 220 A.D.), a centralized governance pattern of irrigation management formed. During this period, the state committed a large amount of financial resources to digging ditches and reclaiming land. The central government was directly involved in building major irrigation projects. Irrigation projects and related affairs were left to local governments. Local officials were often charged with direct responsibility for building and operating irrigation works.

The Tang and Song Dynasties (from 618 A.D. to 1279 A.D.) marked the heydays of the development of China's feudal society and also a period of big development in irrigation. During this period, the official institutions governed by law were thoroughly developed and the state control over irrigation reached its peak in ancient China. The Tang dynasty promulgated the Water Law, the first of its kind in Chinese history, which covered a wide range of contents, with detailed regulations on the use of irrigation water. The Tang and Song dynasties each had water departments under the project ministry to manage and oversee irrigation projects. The irrigation area was managed by officials sent down by the central government. There were specific rules on the organizational setups of irrigation area management organizations. Even the grassroots management personnel were appointed by officials. In the Tang dynasty officials were directly involved in the installation of water measurement facilities and the formulation of rules for the allocation of irrigation water. (Gu, 1997)

The state investment in irrigation began to be reduced after the Tang dynasty. The money needed for building irrigation works had to be shared by water users, who were also obliged to pay operational fees or pay in labor or in grain to get the rights to use water. This became a common practice in later dynasties. In the Song dynasty, the government encouraged nongovernmental investments to build irrigation projects. With the increase in small irrigation works built by nongovernmental forces, local folks began to participate in water management (Wang, 2005).

After the Song dynasty, while the government maintained its controlling power of irrigation, the importance of nongovernmental forces gradually increased. During the Yuan dynasty (1206 A.D. – 1368 A. D.), management personnel of grassroots irrigation areas were no longer directly appointed by the government, but were democratically elected or recommended. Up to the Qing dynasties (1644 A.D. – 1911 A. D.), grassroots irrigation management system was combined with the folk rules, bringing the autonomous management flourishing. The state promulgated few laws on irrigation, but continued what had been established in the previous dynasties and made them common practice, which was enforced by virtue of the folk rules and traditional ethics. This was known as an unofficial system represented by the folk rules and agreements, which played a tremendous role in irrigation management (Wang, 2005).

Compared with the previous dynasties, the government role in irrigation declined dramatically in the Qing dynasty. In this period, the state force gradually phased out of specific irrigation affairs and turned to macro regulation, giving way to local folk rules and regulations (Wang, 2005). Thus a self-organizing pattern of irrigation management emerged in this period, which was most obvious during middle and late Qing period (around 18th and 19th centuries).

Considering China's historically centralized and unitary political system, the following interesting questions will then be raised: Why did irrigation self-organization emerge in

Qing dynasty? And what factors drove this transformation of governance in irrigation management? This paper aims to use the diagnostic approach that Ostrom (2007) propounded to explore the answers of the above questions. As a tentative application of the SES framework, this work is not only expected to give an explanation to the governance pattern changes of China's irrigation management in history, but also attempting to provide some theoretical insights to the application of the SES framework.

3. EXAMINATIONS OF THE SECOND-TIER VARIABLES

It is evident in Chinese history that the users' self-organizing to management irrigation system was so popular that it can be regarded as a general pattern in the 19th century. Of course, the institutional arrangements in different places were diverse, since China has a huge territory. This paper takes Shanxi Province as the main subject and study background because Shanxi Province has a high level of self-organization in North China and was typical in many aspects in irrigation management. But this didn't mean Shanxi Province was a special case. Comparing with Shanxi Province, there were some differences in degree or style of self-organization, but not a distinction in essence. Thus I may also mention some other provinces except Shanxi Province in the following contents. It is also necessary to indicate that the emergence of the pattern of self-organization in Qing China was not a sudden phenomena but a continuous process in history, which can be regarded as the result of evolution in a long history.

This section will examine the second-tier variables potentially associated with self-organization in SES framework indentified by Ostrom (2009). I will introduce briefly the evolution of these variables in Chinese history, especially the condition in Qing dynasty. Due to space limitations, I will not introduce the changes of the other second-tier variables in SES framework.

3.1 Size of irrigation system (RS3)

Size has been regarded as important factor for self-organization in many researches (Araral, 2005; Meinzen-Dick, 2007). Very large territories are unlikely to be self-organized given the high costs of defining boundaries, monitoring use patterns and gaining ecological knowledge (Ostrom, 2007). Thus it seems smaller irrigation system has more possibility to develop self-organization.

The expansion in scope of irrigation self-organization accompanied the dramatic increase of small irrigation works built by local people in Qing dynasty. Compared with the previous dynasties, the importance of the central government in irrigation project and institutions supply dropped greatly. According to Chi (1963), in Shanxi Province, the number of canals built was 97 during the Ming dynasty, and 156 during the Qing dynasty, whereas the total cumulative number recording in two thousand years before Ming dynasty was only 136. The small water works built by nongovernmental investments increased remarkably during this period, which can be partly contributed by the flourishing of business in this province.

In the middle and late periods of Qing, most small irrigation systems were managed by local people. The small irrigation works I mentioned here normally denoted the scales within village or cross-village not beyond county. Large irrigations system, especially cross county works, were still subject to official management. In these systems, the irrigation areas below the sluice gates were subject to management by the local people. Thus large irrigation systems were an example of co-management between officials and farmers.

3.2 Scarcity (RS5)

Water scarcity will encourage users to invest in self-organization and has a significant effect on the likelihood of farmers' participation (Wade, 1994; Araral, 2005). The provinces of Shanxi locates in the arid and semi acrid northwest of China. In the periods of Ming and Qing dynasties, the ecosystem deteriorated severely with population growth, which worsened the effects of droughts.

Take the Shanxi Province as example. The forest coverage in the early Ming period was about 30 percent, and declined to 15 percent in middle Ming, and only 10 percent in the end of Qing dynasty (Xing, 2000). This deforestation was mainly caused by large scale land reclamation, driving soil erosion and decreased runoff. Ecosystem deterioration brought more frequent drought and famine. According to statistics in the Fenhe Irrigation Area of Shanxi Province, from 142 B.C. to 618 A.D., there were 8 drought years, in average once per 97 years; from 618 A.D. to 1260 A.D., 19 drought years, once per 34 years; and in Ming and Qing dynasties, droughts happened more frequently, from 1368 A.D. to 1911 A.D., 40 drought years, once per 14 years (Xing, 2000). This situation made the water resources scarcer and the farmers had to pay more attention to water works development and water resources efficiency.

3.3 Local collective-choice autonomy (GS6a)

Having collective-choice autonomy to make one's own rules is important for self-organization shown in many empirical studies (Ostrom, 1990; Haller and Merten, 2008). Actually, it is also important part of self-organization itself.

From the first empire of Qin (221 B.C.-206 B.C.), China built up a centralized political system, and a hierarchical administrative system was introduced from central level to local level. In the Tang dynasty, a set of management institutions was executed by state agents commissioned by the central government all the way down to the local level. Basically, most irrigation affairs, including the installation of water allocation facilities and the formulation of allocation mechanism, were undertaken directly by the government officials. People had to apply for licenses to use water, and the areas of all the irrigated land had to be registered. Such application was done every year.

After the Tang dynasty, driven by the motivation to lower costs, the micro management regime transformed from official agent commissioned by the government to nongovernmental organizations operated by local people. But the grassroots nongovernmental organizations needed the official support of the government. This means some extent autonomy had appeared in local affairs governance including irrigation management. In Ming and Qing period, local autonomy was developed further and a large number of local irrigation organizations appeared, which were managed by local groups and whose personnel were selected by localities. The state did not have a hand in routine operations of the irrigation works. The state role was expressed in granting the local management rules a legal status and ensured that they were observed. When disputes occurred, the state would act as an arbitrator (Bai, 2003).

In Ming and Qing period, the booklet of canal regulations became popular and played a dominate role in the micro irrigation management. The canal regulations made detailed stipulations for specific canals or irrigation areas, such as the water rights or water allocation principles, users' obligations, water facility maintain, and conflict resolution, etc. Normally the canal regulations originated from spontaneous order such as folk custom or precedent, and developed by local people, which increased the likelihood of congruence between rules and local conditions. While the canal regulations also commonly got the support of the government, from which the canal regulations with folk characteristics got the official authority. For some important canal regulations, the government possibly chose to indirectly intervene or even direct participation. In the provinces of Shanxi and Shaanxi, some canal regulations had a history of more than five hundred years, which were obeyed strictly generation by generation and became more and more precise.

3.4 Number of users (U1)

Though group size is always relevant with self-organization, Ostrom argues that its effect depends on other SES variables and the types of management tasks envisioned (Ostrom, 2009). In this study, I believe that more users reduce the water resources amount of each user and increase the importance of irrigation water, which draw demands for institutional change.

Before Qing dynasty in imperial China, the population of the country was no more than one hundred million in most periods. Normally in the flouring period of the major dynasty, the population ranged between 40 million and 60 million (see Table 2). During the Qing dynasty, the population experienced remarkable growth, increasing roughly fourfold from around 100 million in 1700 to 430 million in 1850. This growth results a rapid deterioration of the human – land relationship, and the late Qing in the end of 18^{th} century had fallen into the Malthusian Trap (Ho, 1959).

Table 2. The Population Registered of China

Year	Households	Persons
Xihan dynasty, 2 A.D.	12,333,062	59,594,978
Donghan dynasty, 157 A.D.	10,677,960	56,486,856
Shui dynasty, 606 A.D.	8,907,536	46,019,956
Tang dynasty, 755 A.D.	8,914,709	52,919,309
Song dynasty, 1109 A.D.	20,882,258	46,734,784
Yuan dynasty, 1209 A.D.	13,196,206	58,834,701
Ming dynasty, 1393 A.D.	10,652,789	60,545,812
Qing dynasty 1741 A.D.		143,411,559
Qing dynasty, 1820 A.D.	49,489,715	264,278,228
Qing dynasty, 1851 A.D.		431,894,047

Sources: Ho, 1959.

Taking the case of Shanxi Province, it presented a similar trend of the population growth with the whole country (See Table 3). From middle Tang (713 A.D.-741 A.D.) to middle Ming (1542), the population of this province grew from 2.33 million to 5.07 million, and increasingly grew to 16.4 million in late Qing (1875). The rapid growth of population brought the decrease of per capita farmland (Wang and Zhang, 2006), and the increase of conflicts around water utilization (Xing, 2000). There has a common view that the deterioration between human and natural resources was one of main factors to impel more precise rules of irrigation management in the Qing dynasty.

Table 3. The Population in Shanxi Province

Year	Persons
Xihan dynasty, 2 A.D.	1,640,000
Donghan dynasty, 140 A.D.	770,000
Xijin dynasty, 280 A.D.	630,000
Shui dynasty, 609 A.D.	2,050,000
Tang dynasty, 713-741 A.D.	2,330,000
Yuan dynasty, 1291 A.D.	400,000
Ming dynasty, 1393A.D.	4,070,000
Ming dynasty 1542 A.D.	5,070,000
Qing dynasty, 1820 A.D.	14,600,000
Qing dynasty, 1875 A.D.	16,400,000

Sources: Wang and Zhang, 2006; and Ho, 1959.

3.5 Socioeconomic attributes of users (U2)

Some field studies have indentified multiple socioeconomic attributes of users that affect whether self-organization occurs, among which the variable of heterogeneity was examined intensively. The links between heterogeneity and collective action are complex (Heckathorn, 1993). Poteete and Ostrom (2004) argued that the relationship between heterogeneity and collective action was nonlinear and contingent upon many other factors. Considering there are various forms of heterogeneity (Vedeld, 2000), I would like to focus on the heterogeneity in wealth and entitlements. Veldeld (2000) concluded that collective action is often enhanced by political elites and leaders being a bit better endowed and a bit wealthier than the average community members. Some inequality of resource endowments is necessary to facilitate initiatives, by enabling some actors to bear the costs of taking a leadership role (Balland and Platteau, 1995). Those with greater endowments are willing to bear a disproportionate share of the initial costs of organizing institutional arrangements in order to stimulate movement. The presence of wealthy and knowledgeable participants early in the process may encourage trust. In turn, inequality in distribution of benefits in the later stages of cooperation may reduce trust and reputation and constrain the emergence of further cooperation (Ostrom, 2007).

The above theory can be well used to explain the role of heterogeneity in self-organization in the imperial China. Land entitlement was the main wealth and water entitlement usually attached on it. Normally in the beginning of a major dynasty, the state would allocate the right of the land equally. As time passed to the middle and late of that dynasty, there would be a concentrated trend of land right with land annexation by wealthy or powerful groups, and the inequality of wealth increased and became an important factor to drive the collapse of the dynasty. This trend represented more visible in the middle and late period of Ming and Qing dynasties, partly because the rural society was affected by the markets forces and business development during this period. The result was the emergence of the social class of local gentry and power families, which played multiple roles of financing, organizing, conflict resolution, and decision-making in the autonomous governance of rural society. I can also regard the role of local gentry and power families as leadership, which will be introduced further in the following section.

3.6 Leadership (U5)

When some users of any type of resource system have entrepreneurial skills and are respected as local leaders, self-organization is more likely (Wade, 1994; Ostrom, 2009). For example, the presence of college graduates and influential elders had a strong positive effect on the establishment of irrigation organization in a stratified sample of 48 irrigation systems in India (Meinzen-Dick, 2007).

In middle and late Qing period, local elites played more and more important function in local affairs governance, which made it possible for the government to shirk from the grassroots management. Among the local elites, two kinds of forces were noticeable, one was clan power, and another was the gentry class. In many places, the clan elder had plenty of power within the clan, which can also extend the power to local community authorized by the government.

The gentry class was likely more important in Qing dynasty, which normally included two kinds of people: local intellectuals who excelled in the imperial examination system and had not yet secured an official position, and retired officials returning home. The local gentry got authority by their knowledge and the close relationship with the government. And the government also respected and aided the position of gentry class. Fairbank (1983) even said that any county officials nominated by the emperor could not govern without the cooperation of local gentry. In rural society of the Qing period, gentry played roles in many aspects, e.g., providing donation to the building and repairing of water facilities, formulating the folk rules, monitoring and sanctioning of rule enforcement, mediating the conflicts among villagers, and bridging the villagers with the government.

For the canal management, many places built nongovernmental irrigation organizations as mentioned above, which were normally comprised of canal chief, ditchmen, and water staffs. The canal chiefs played entrepreneurial role in irrigation management. Nominally the chiefs were elected by water users, but in fact they were often recommended in forms of mass discussion by local gentry. In some canals irrigating large area, the recommended chief would get the official appointment. A typical example of irrigation organization in Hongdong County of Shanxi Province during Qing dynasty, is shown in Figure 2. The Daily Management Organization was operated by the Monitoring Canal Chief, assisting by three Vice Canal Chiefs, through three Specialized Canal Chiefs and a number of Ditchmen. And the Power Organization was the Canal Gentry Meeting with a few committee members, and its function was equal to decision board of canal affairs.

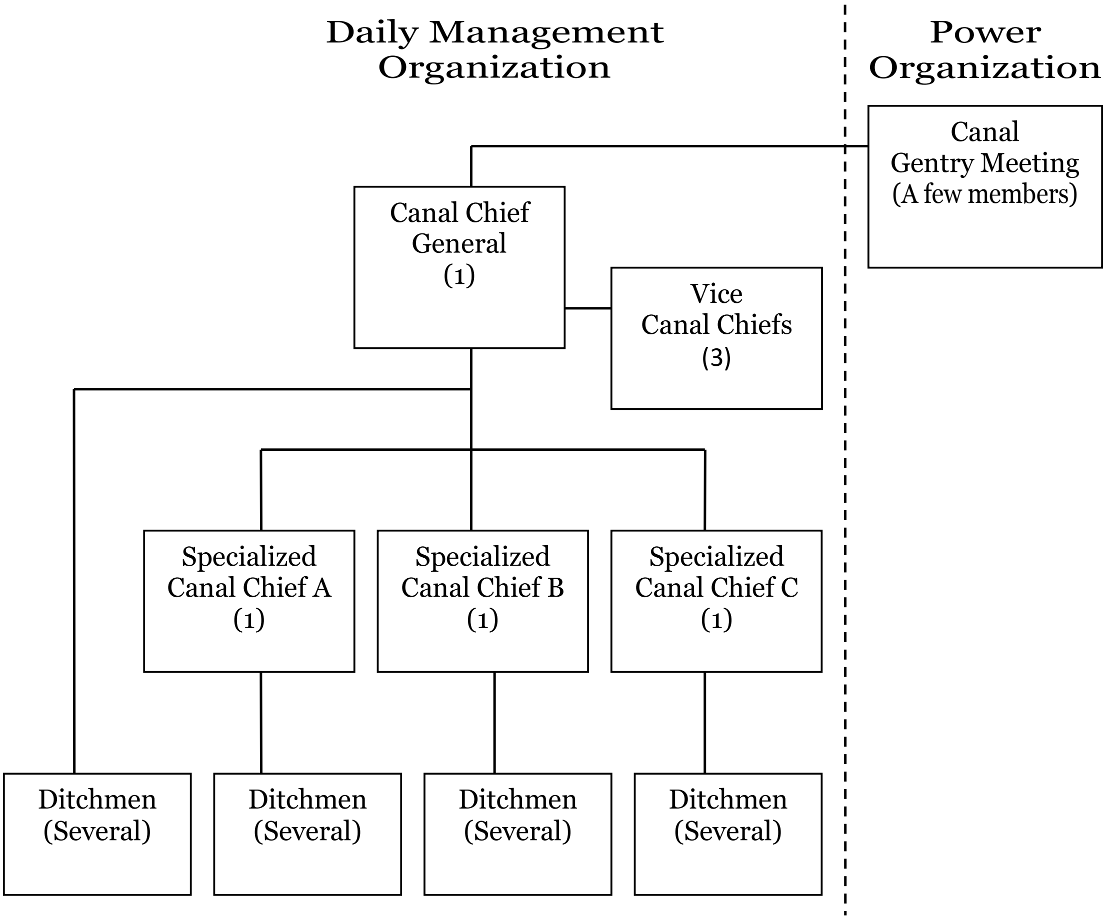

Figure 2 A typical irrigation organization in Hongdong County
Source: Zhou (2005).

3.7 Norms/Social capital (U6)

Users who share moral and ethical standards will face lower costs of collective action (Ostrom, 2005). An analysis of 2048 systems in the Philippines found the social capital represented by frequent face-to-face communication had a significant effect on the likelihood of farmers to pay for services (Araral, 2005). And the results of a study on 48 irrigation systems in India display that the number of temples increases the likelihood of organization for irrigation, and the social capital generated by religion seems to have a stronger influence on organization than social capital created by cooperatives (Meinzen-Dick, 2007).

In Ming and Qing period, the governance system of irrigation was mainly comprised by various folk rules and agreements, whose maintenance were relied on moral and religious forces. Since the village communities were relatively stable in traditional agricultural society, the villagers faced strong moral constraints not only from the formal rules and punishment but also from traditional custom, public opinion, and personal reputation, to keep the shared norms of trust and reciprocity in natural resources management. In many places, this moral force was enhanced further by religion. Though Confucianism was regarded as the official ideology in most period of imperial China, there were actually diverse forms of religion in different regions. Generally, the ancestor worship was more popular and the clan hall played the role of social capital in southern China, while the idol worship particularly prevailed and the temple was the index of social capital in northern China.

In many regions of Shanxi Province, the worship of water spirit and special sacrificial ceremony had been developed, for water was so important for local people. Xing (2005) studied a case of water spirit worship among 36 villages in Jin River Basin of Shanxi Province. The Jin Temple was the main memorial hall for the people in this river basin. The interesting thing was that the main idol dedicated in this temple evolved in the history of the past 2500 years. In the beginning, Tangshuyu, the first prince of ancient Jin country, was the deity of this temple. To the 11th century in Song dynasty, a female deity of Saint Mother was adored and replaced gradually the Tangshuyu as the main idol in Jin Temple, because people confused Saint Mother with water spirit. In the 16th century in Ming dynasty, another deity of Water Mother got the worship of people in 36 villages, and grand sacrificial ceremony to Water Mother was held every year from then on to now (Xing, 2005). The rise of Water Mother can be attributed to the increasing water scarcity with population growth in Ming and Qing period. And the water spirit worship played important role to keep common values, support water rules, and prevent social conflicts in the river basin.

3.8 Knowledge of social-ecological system (U7)

When users share common knowledge of relevant SES attributes, how their actions affect each other, and rules used in other SESs, they will be easier to organize (Berkes and Folke, 1998; Ostrom, 2009). This is also true for irrigation management in China.

In most of the irrigated area of China, there is a long history of irrigation activities. Many places in the provinces of Shanxi and Shaanxi have irrigation tradition more than thousand years, and the booklet of canal regulations continued for several hundred years. To the period of Qing, the farmers had been very familiar with irrigation upon both physical knowledge and related rules. For example, in Hongdong County of Shanxi Province, a folk proverb went round in late Qing period that everybody respected the booklet of canal regulations as golden laws and a precious precept. The canal regulations were so constant and sustainable that it could be regarded as the “constitution” of riparian people around the canal.

As the supplement of booklet of canal regulations, the inscriptions on the stele were very common in many villages in Shanxi Province. The contents of the inscriptions on the stele were divers, e. g., history of the canal construction, memorial to contributors or donors, regulations for canal affairs, and judicial precedent. The built of some important steles often got the support from the government or was made directly by the government, which strengthened the authority of the inscriptions on them. The inscriptions on the stele were well known by folks and weighed heavily in the mental world of local people.

3.9 Dependence on irrigation (U8)

In successful cases of self-organization, users are either dependent on the resources system for a substantial portion of their livelihoods or attach high value to the sustainability of the resource (NRC, 2002; Ostrom, 2009).Thus the effect of this variable is obvious for self-organization, the more important of the resource to users, the higher likelihood for users' taking efforts.

China is a county highly depending on irrigation. It would have been impossible for China to achieve a high level of agricultural productivity in the imperial times without the development of irrigation systems (Chi, 1963). As one of the most important areas of agricultural production, the provinces of Shanxi and Shaanxi had a higher dependence on irrigation. For example, the Hongdong County of Shanxi Province, located east of the Loess Plateau with an arid climate, frequently suffered from water shortages. This condition made water use became the first priority in this area, and the governors of this county even regarded the irrigation as the most important local affair.

As the above has mentioned, in the period of Qing, the scarcity of water increased with the remarkable population growth. The implication of this change was the importance of irrigation increasing further, which can be reflected by the economic value of irrigation water. The population at the beginning of the Qing Dynasty soared from 143.41 million in 1741 to 432.16 million in 1851. Although the cultivated areas continued to increase, the average on the per capita basis dropped steadily. Before the Northern Song Dynasty, the cultivated land per capita averaged about 10 *mu* (1/15 a hectare). By the middle of the Qing Dynasty, the per capita cultivated land dropped to less than 4 *mu*.

In this context, the value of irrigation water rose to a considerable level. The paddy fields had to pay more grain for water than dry farmland. In the Guanzhong Area of Shaanxi Province during the reign of Emperor Qian Long, "grain for water" accounted for about a quarter of the crop tax and the payment varied according to different grades of paddy fields. The principle was "the volume of water used by burning incense; tax is paid on the use of water." It was exactly because of the rising value of water that driving new rules introduced to raise the efficiency of water use.

4. INTERACTION AND LINK CONTEXTUAL SETTINGS WITH KEY VARIABLES

4.1 An in-depth explanation of irrigation self-organization

Based on the analysis of the variables above, I now attempt to link these variables together to understand the emergence of self-organization pattern in Qing China. A causal relationship map is shown in Figure 3, in which I only display the major interactions among the key variables.

Firstly, let us see the variable of Local collective-choice autonomy (GS6a), which is one of the key variables to make self-organizing possible, especially in a centralized political system. From 10th century of Tang dynasty, the government had allowed a certain degree of autonomy in rural government. In the period of Ming and Qing, this autonomy in village level had been expanded further. Especially in Qing dynasty, the government implemented policies to support the power of clan and gentry and endowed legal force to clan elder and gentry. Additionally, the Qing government carried out another policy supporting "Xiang Yue", which were the folk rules formulated by the clan elder and gentry in accordance with local conditions under the guidance of official ideology. All these policies shaped the rural autonomy and promoted the development of nongovernmental irrigation organizations.

Secondly, I turn to the variable of Leadership (U5), which provided important support to local collective-choice autonomy. As mentioned above, the emergence of clan power and gentry were noticeable in the Qing dynasty, and this could be contributed to the changes of Socioeconomic attributes of users (U5). The increase of heterogeneity of villagers could be further attributed to the Economic development (S1), a variable in contextual settings.

Thirdly, the variable of Norms/Social capital (U6) interacted with Local collective-choice autonomy (GS6a) and composed the core component of the self-organization pattern in Qing China. The shared norms and social capital had became strong in Qing dynasty, not only the reasons that the government policy to support folk rules and the development of local collective-choice autonomy, but also the changes of some other variables. One was the variable of Knowledge (U7). In the Qing dynasty, the local people had abundant knowledge of both the physical world around the irrigation area and the rules system. Another variable of History of use (U3) can strengthen the social capital and shared norms. In the late Qing period, many irrigation systems in northern China had a long history of several hundred or even more than thousand years, and this was very helpful for local people to accumulate knowledge and shape stable norms. Meanwhile, the variable of Dependence on irrigation (U8) was also important. The increase of importance of irrigation water in Qing dynasty had a close causal link with the changes of norms and rules related with irrigation management, and also provided more incentives for local people to develop the knowledge around irrigation.

Then some driving factors could be further recognized to understand the changes of Dependence on irrigation (U8) in the complex relationship chains. One factor was the dramatic growth of Number of users (U1), which was further attributed to the contextual variable of Population trends (S2). Another factor was the rising of Scarcity (RS5), and it also increased the importance of water resources.

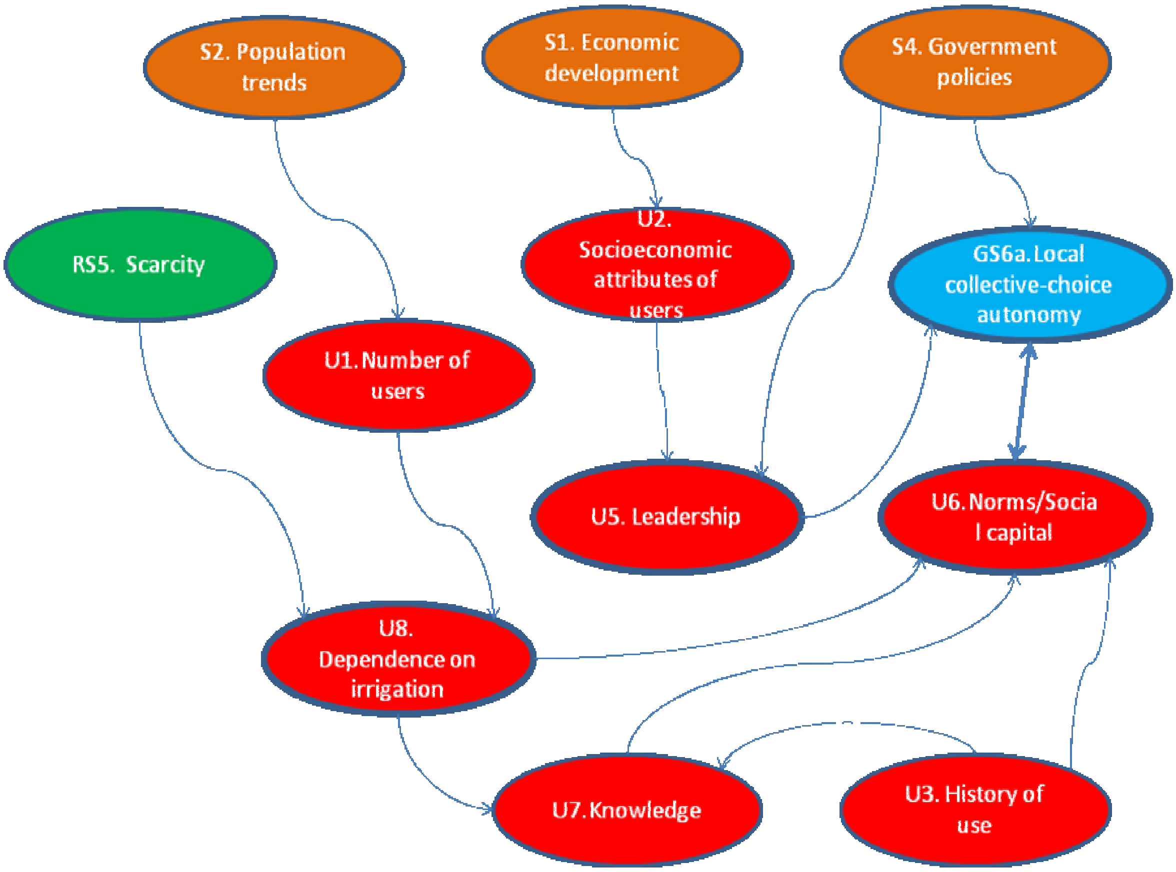

Figure 3 An explanation of irrigation self-organization in Qing China

Finally, if we observe the whole Figure 3 and seek for the answer of the changes of the variables in the subsystems of Governance System (GS) and Users (U), it was obvious that the changes of variables in contextual settings and another subsystem of the Resource System (RS) provided the driving forces. In the Social, Economic and Political Settings, the variables of Economic development (S1), Population trends (S2) and Government policies (S4) can be regarded as the exogenous variables affecting the variables in the subsystems of Governance System and Users. For the subsystem of Resource System, the variable of Scarcity was the exogenous variable having an impact on the other subsystems.

4.2 Explaining the changes of resource system

The changes in the Resource System could produce a shock to the Governance System and Users as above analysis. Nevertheless the changes of Resource System may not be regarded simply as natural phenomena, but a result interacting with the variables in other components. A further understanding for the changes of Resource System in a broader perspective is shown in Figure 4.

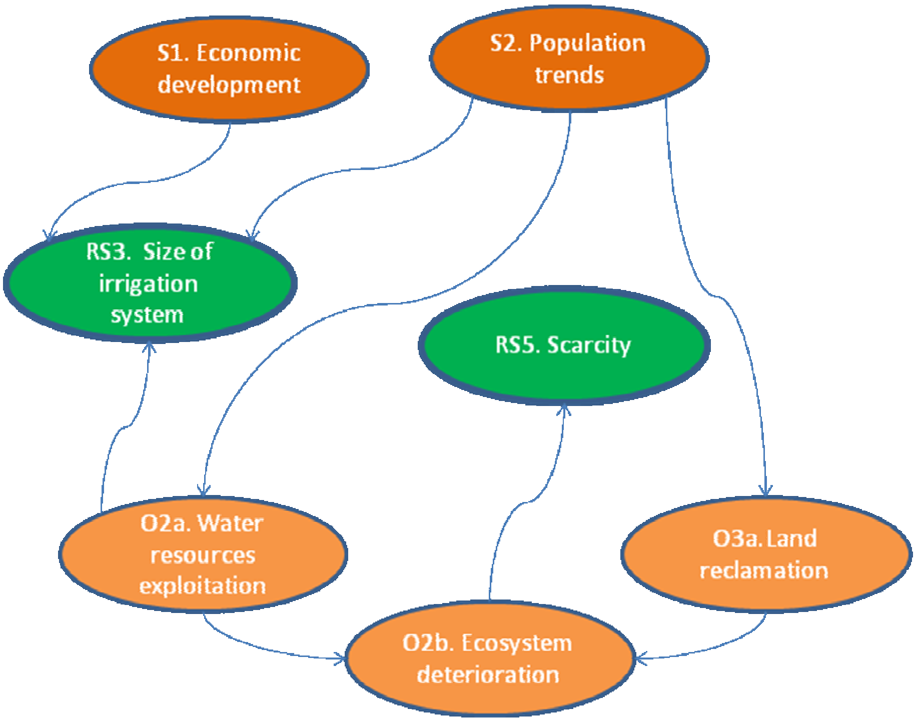

Figure 4 Explanation of the changes of resource system in Qing China

One initial variable was the Population trends (S2) in the contextual settings. The dramatic growth of population in Qing China drove the changes of Outcomes, including Land reclamation (O3a) and Water resources exploitation (O2a), which jointly led to Ecosystem deterioration (O2b). The Scarcity (RS5) of water resources was a result of decreasing productivity of the system caused by the Ecosystem deterioration (O2b).

The Water resource exploration (O2a) induce by population growth, had another effect that the demand to water infrastructure and facilities increased greatly in Qing dynasty, which brought about plenty of small water works and smaller Size of irrigation systems (RS3). And the contextual variable of Economic development (S1) provided the financial resources of new works construction.

4.3 Explaining the population trends

According to the above analysis, the variable of Population trends (S2) seems the most significant factor led to the great changes of the SESs in Qing China. As the figures cited before, the population grew fourfold during the period of Qing, which was also the most remarkable growth in the imperial time of China. Thus it raised another interesting question - why did a dramatic growth of population happen in Qing dynasty?

We would like to give an explanation for such a question from the perspective of interactions of variables within the contextual settings (See Figure 5). From the building of Qing dynasty in the midst of 17th century, it attained Political stability (S3) lasting more than 200 years, and this naturally promoted population growth directly and the Economic development (S1) affecting the population growth indirectly. Whereas the similar routine happened repeatedly in each major dynasty and it was not very special for Qing dynasty, except that the peaceful period was longer indeed.

More important factors well known by historians (Ho, 1959), were the Government policies (S4) and the changes of agricultural Technology (S6). In 1724, the third emperor of Qing dynasty, Yongzheng, promoted an important fiscal reform entitled "Tan Ding Ru Mu", which abolished the poll tax according to population amount and levied merged taxes according to the measurements of farmland. And this policy stimulated the growth of population in the following two centuries. Another important factor was the imports of new types of crops, including sweet potato, corn and potato in the late Ming period before the 17th century. Since these crops were high productive and suitable for dry land and mountain land, they were widely planted in Qing period and expanded food sources and increased grain yields, thus stimulated population growth strongly. The sweet potato, corn and potato were originally produced in America. After Columbus found the new continent of America in 1492, they were spread to the other continents in succession. Therefore, the changes of Technology (S6) were further caused by another contextual variable of Globalization (S7) as shown in Figure 5.

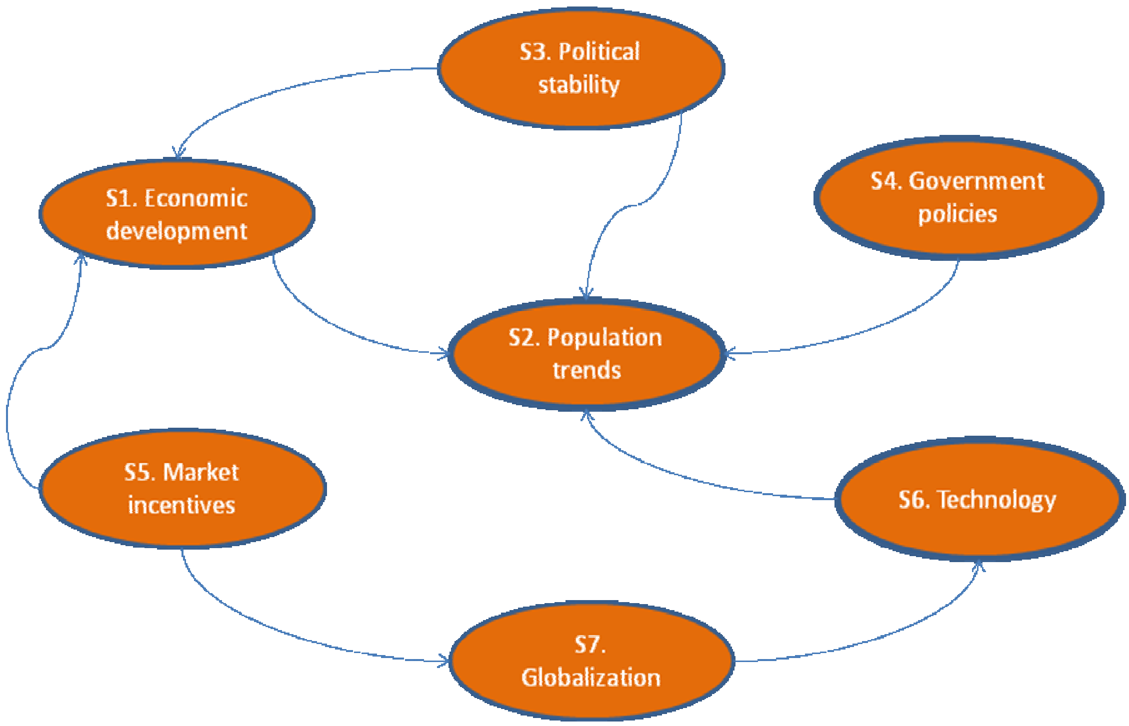

Figure 5 Explaining the population trends in Qing China

5. CONCLUSIONS

This paper adopts the diagnostic approach that Ostrom (2007) proposed to explain the emergence of irrigation self-organization in Qing China. The framework for analyzing the social-ecological system provides the possibility to conduct a systemic diagnosis for such a question. Among the numerous variables in the system, the population growth seems the most remarkable factor driving the changes. It not only brought the direct effect of increasing users but also resulted in ecosystem deterioration and thus the declining of water resources. Both the changing contextual settings and deteriorating ecosystem produced external impacts on the social system. As the response to external pressure, the social system changed to adapt to the changing situations. In this context, the self-organization emerged in Qing dynasty, effectively improved the performance of irrigation systems to afford the growing population. Thus the self-organization provided the adaptation to support the sustainable development of social-ecological system.

Within the social system, the responses to the external changes happened in multilevel and diverse forms. In this case, the subsystem of governance system adjusted in different dimensions, including the development of nongovernmental organizations and social network, the changes of property-right systems, and more precise operational rules. For the subsystem of users, the shared norms and social capital had been intensified to response the external challenges. Meanwhile, the political structure and government policies created a macro environment to develop the local collective-choice autonomy, and the population growth and economic development provided the physical capital and human capital to support self-organization. From this perspective, the emergence of irrigation self-organization was more likely after a long-term continuous process of adjustment and change, and played a vital role to sustain the stability of social-ecological systems.

There are also some theoretical insights that draw from the application of the SES framework in this study. Basically, this analysis shows that the SES framework is robust as a powerful tool to diagnose the complexity in the social-ecological system. Also, it has been verified that the variables indentified by Ostrom (2009) are significant to affect the likelihood of self-organization. Besides, some other variables such as the history of use, were displayed to be associated with the development of irrigation self-organization, as Ostrom has predicted that in particular cases, other variables may enter the diagnostic analysis (Poteete, Janssen and Ostrom 2010). Particularly, this study reveals that the economic, social and political settings are very important and provide initial forces or supporting environment for the development of self-organization. Some contextual variables, including not only the government policies mentioned by Meinzen-Dick (2007), but also population trends, economic development, globalization and technology seldom mentioned in prior literature, are proved to be important in this study.

In addition, this study also demonstrates the complex interactions in the social-ecological system, not only the interactions between different subsystems, but also within the subsystem such as the variables in Users or Governance system. Even the variables in the contextual settings have complex interactions. Identifying these interactions and revealing the causal relationship among the variables in the SESs, is a big task for social scientists, and better theories can be developed to promote knowledge accumulation with the guidance of the SES framework. There is undoubtedly big potential along this direction in the future.

Considering China has the largest irrigation systems and long history of irrigation management, it can provide abundant empirical materials to test or develop related theories. This paper is just a beginning and its main value is to snap a whole picture of irrigation management in the imperial China. Based on this work, the next step can turn to specific case study and cross-case comparison. I hope more empirical studies will be conducted to contribute theoretical development.

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