Internal Stresses and Social Feedback Mechanisms in Social-Ecological Systems:

A Multi-Method Approach to the Effectiveness of Exit and Voice

by

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ABSTRACT

My research is motivated by a rule of thumb that no matter how well a system is designed, some actors fail to fulfill the behavior which is needed to sustain the system. Examples of misbehavior are shirking, rule infraction, and free riding. With a focus on social-ecological systems, this thesis explored the effectiveness of social feedback mechanisms driven by the two available individual options: the exit option is defined as any response to escape from an objectionable state of affairs; and the voice option as any attempt to stay put and improve the state. Using a stylized dynamic model, the first study investigates how the coexistence of participatory and groundwater market institutions affects government-managed irrigation systems. My findings suggest that patterns of bureaucratic reactions to exit (using private tubewells) and voice (putting pressure on irrigation bureaus) are critical to shaping system dynamics. I also found that the silence option – neither exit nor voice – can impede a further improvement in public infrastructure, but in some cases, can improve public infrastructure dramatically. Using a qualitative comparative analysis of 30 self-governing fishing groups in South Korea, the second study examines how resource mobility, group size, and Ostrom's Design Principles for rule enforcement can co-determine the effectiveness of the voice option in self-controlling rule infractions. Results suggest that the informal mechanism for conflict resolution is a necessary condition for successful self-governance of local fisheries and that even if rules for monitoring and graduated sanctions are not in use, groups can be successful when they harvest only stationary resources. Using an agent-based model of public good provision, the third study explores under what socioeconomic conditions the exit option – neither producing nor consuming collective benefits – can work effectively to enhance levels of cooperation. The model results suggest that the exit option contributes to the spread of cooperators in mid- and large-size groups at the moderate level of exit payoff, given that group interaction occurs to increase the number of cooperators.

DEDICATION

To my wife, our son, and our parents and siblings who have supported me.

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CHAPTER 1

INTRODUCTION

1.1. Introduction

Human interaction with nature does not occur in a vacuum, but instead is mediated by human-made infrastructures that help produce and distribute a stream of economic value from natural resources (Anderies, Janssen, and Ostrom 2004; Anderies, Janssen, and Schlager 2016). In many agricultural systems, for example, shared canals and dams (hard human-made infrastructures) help farmers obtain a steady supply of water in the face of the threat of environmental variability. Besides hard human-made infrastructures, a variety of rules (soft human-made infrastructures) regulate the use of resources and maintain resource stocks. Thus, both infrastructure maintenance and rule compliance are critical to sustaining social-ecological systems (SESs) in which natural resources are extracted and managed to support livelihoods of resource users. However, numerous empirical studies point out that maintaining shared physical infrastructure and rule conformance at a sufficient level is a key challenge for sustainable governance of SES (Ostrom et al. 2002; Janssen, Anderies, and Cardenas 2011; Anderies et al. 2013).

In a SES where an agency (i.e., irrigation bureau) is in charge of managing shared infrastructures, mismatches between benefits and costs can result in poor infrastructure maintenance (Ostrom, Lam, and Lee 1994). In a self-governed SES where resource users themselves provide shared physical infrastructures, they may be tempted to utilize the infrastructure with no contribution and violate the appropriation rules to overexploit for private benefits (Ostrom 1990). When subjected to the internal stresses such as shirking, rule infraction, and free riding, SESs will be in decline unless social feedback mechanisms work properly to cope with the misbehaviors and their negative impacts on SESs (Anderies 2015). Given the importance of social feedback mechanisms to sustainable governance of SESs, this thesis investigates two questions: **what actions are available to individuals to respond to a decline in system performance** and **under what conditions the individual actions can help sustain SESs?**

Hirschman (1970)'s discussion on *exit* and *voice* yields valuable insights into parsimonious classification of the possible actions taken by those who are faced with a decline in system performance. In the broadest sense, exit is defined as any response of dissatisfied people to escape from (or avoid) the situation where they are dissatisfied. Examples of the exit option include a consumption of a better-quality product instead of a currently used product in decline, and a switch from a current organization to a better-performing one. As organizations experience a loss of monetary and human resources due to the exit option, they will likely improve goods and services to address customer retention or to restore membership size. (Hirschman 1970). Based on this simple model, the exit option has been considered as an important feedback mechanism for motivating firms and local governments to enhance their performances (e.g., Tiebout, 1956; Ostrom, Tiebout and Warren, 1961).

Another potential response to a decline in organizational performance is the voice option defined as "any attempt at all to change, rather than escape from, an objectionable state of affairs" (Hirschman 1970, 30). Through the voice option, members or customers can articulate their discontent with organizational performance, identify the problems causing a deterioration of the performance, and provide ways to correct the problems. The voice option can be exercised through formal and informal channels aimed at promoting public engagement in enhancing system performance (Hirschman 1970). When shared infrastructures deteriorate because of shirking by infrastructure providers, resource users can make their voice heard through participatory institutions, such as participatory budgeting (World Bank 2013; Boulding and Wampler 2010), participatory planning for operation and maintenance (Bruns 2004), and citizen report cards (Svensson 2005). When concerned about rule infractions in a self-governed SES, resource users can also make their voice heard about how to deal with violations of community rules for managing natural resources sustainably (Ostrom 1990). Although there are such a variety of forms of voice, they all aim to correct misbehaviors by inflicting monetary costs and social pressure on wrongdoers (Hirschman 1970).

The exit and voice options were originally discussed by Albert O. Hirschman to better understand how to improve economic and political systems undergoing decline in system performance. My dissertation extends an application of exit and voice to social-ecological systems which are subjected to human-driven internal stresses that should be managed properly to sustain the systems. Given the two types of social feedback mechanisms (exit and voice), a sustainability question arises as to **under what institutional and contextual conditions the exit and/or voice options can work effectively to sustain SESs.** To explore this broad question, I address the following subquestions in three different domains of SESs including government-managed irrigation systems, self-governed fishery systems, and public goods games:

1. If both the exit and voice option are available to resource users, under what conditions will the two options come into play jointly to improve government-managed irrigation systems?
2. If the exit option is not available to resource users, what set of institutional and social-ecological conditions will help make the voice option work effectively for successful self-governance of local fishery systems?
3. If the exit option is available to resource users, under what socioeconomic conditions will the exit option work effectively for the provision of local public goods?

Using multi-method approach, this thesis answers the three questions above in Chapter 2, 3, and 4, respectively. As shown in Table 1.1, the three chapters use different research methods and domains to examine how exit and/or voice can contribute to improving SESs faced with different internal stresses.

Table 1.1. Research overview

Chapter	Method	Domain	Internal Stress	Individual Response
2	Dynamic mathematical modeling	Government-managed irrigation systems	Bureaucratic shirking	Exit and voice
3	Qualitative comparative analysis	Self-governed fishery systems	Rule infraction	Voice
4	Agent-based modeling	Public goods game	Free riding	Exit

The remainder of this thesis is largely devoted to the analysis of the interplay between the exit and voice options (**Chapter 2**) and to the study of the conditions that could serve to make each of the two options work effectively (**Chapter 3 and 4**). Finally, in **Chapter 5**, I summarize my findings and suggest the theoretical and practical implications for the successful use of exit and/or voice as social feedback mechanisms. In the remainder of this introductory chapter, I address what motivates me to examine the respective research question and provide a brief description of my research strategy to answer the question.

1.2. Government-Managed Irrigation Systems: Exit and Voice

Although over 60% of the total irrigated area worldwide is commanded by government-managed irrigation systems, their performance (i.e., irrigation efficiency) has been generally less than satisfying in many countries (Suhardiman and Giordano 2014; Mukherji et al. 2009; Lam 1998; Burton 2010). In response to decline in irrigation performance, a great deal of policy effort has been made to transform government-managed irrigation systems into either farmer-managed or privatized systems (Johnson III, Svendsn, and Gonzalez 2004; Molle, Mollinga, and Wester 2009).

However, such a fundamental transformation into a particular system has not always generated successful outcomes because of diverse factors affecting post-reform situations, such as bureaucratic resistance (Suhardiman and Giordano 2014) and the absence of market-friendly traditions in water sectors (Easter and Qiuqioing 2014). An important lesson from these experiences is that “there is a need for more research on combinations of institutions, rather than the performance of single institutions in presumed isolation." (Meinzen-Dick 2007, 15205). However, little research effort has been devoted to investigating how a blending of different institutions in a single SES shapes the long-term dynamics of the system.

To fill the gap left by the institutional approach to water governance, I focus on two different institutions that enable farmers to exercise the exit and voice options in response to a decline in government-managed irrigation systems: participatory institutions and groundwater market institutions. Many developing and less-developed countries have increasingly institutionalized farmers' participation ("voice") in dealing with operation and maintenance (O&M) issues while government agencies collect irrigation service fees from farmers (Groenfeldt and Svendsen 2000; Bruns 2004). An expected effect of this participatory institution on an irrigation agency is that some extra direct costs can be inflicted on the agency, since more resources should be invested to cope with farmers' dissatisfaction and demands (i.e., physical infrastructure repair, rule development, and better technology).

Besides the voice option provided by consciously-designed institutions, the exit option could also be promoted by self-organized, informal institutions for water markets. For instance, farmers who are dissatisfied with public irrigation services can instead utilize ("exit to") private infrastructures (i.e., privately-owned tubewells) in a groundwater market institution at the local level (Shah 2009; Wang et al. 2014), thereby reducing the government agency's revenue.

Given that exit and voice come into play jointly to generate a potential monetary loss on a government irrigation agency, it is imperative to better understand under what conditions both options will help sustain government-managed irrigation systems. The conditions of interest in this study are patterns of bureaucratic reactions to exit and voice. The agency in my model is assumed to be a typical bureaucratic organization that does not make an immediate response to a small amount of monetary loss. Such bureaucratic shirking occurs not only because there are no appropriate incentives for the irrigation bureau to keep aging infrastructures in good condition (Ostrom, Lam, and Lee 1994), but also because the bureau prefers to undertake new irrigation infrastructure projects (Molle et al. 2009). On the other hand, the agency has little or no incentive to leave the infrastructures largely dysfunctional, since the collapse of the irrigation system can lead to more fundamental reforms including an agency shutdown.

To capture such self-interested reactions of an irrigation agency, I assumed a piecewise linear form of reaction function relating O&M effort by the agency to monetary pressure from exit and voice: no effort into O&M is made for a small loss; the effort linearly increases within a range of the mid-size loss; and lastly, no effort can be made again if the loss exceeds a certain large amount of loss. Thus, agency's reaction function has two characteristics: *sensitivity* characterized as the minimum amount of monetary loss beyond which O&M efforts start to be made by the agency; *durability* characterized as the maximum amount of monetary loss below which the efforts are sustained in the face of increasing losses.

In Chapter 2 using this model of farmers-agency interactions, I address the question of how the coexistence of participatory and groundwater market institutions affects the dynamics of government-managed irrigation system in two stages. First, I explore how variations in the two reaction characteristics may induce regime shifts (i.e., public, private, and mixed irrigation economy) and altered a capacity of the system to be resilient to an external shock (e.g., typhoon). In the first analysis, I assume that all farmers exercise either the exit option or the voice option, i.e., no silent farmers who use government-managed irrigation infrastructure without making their voice heard. The results from this assumption will be compared to the results of my second analysis which assumes that there are silent farmers in government-managed systems. By comparing the results of the two model analyses, I can examine how silent farmers play a key role in changing system dynamics.

1.3. Self-Governed Fishery Systems: Voice

Hirschman argues that an organization which experiences membership declines caused by the exit option will try to search for ways and means to correct whatever problems have made members leave the organization (Hirschman 1970). However, exiting to other organizations is not always available to common-pool resource users who have long been self-organized to manage their resource systems under communal property. This is because the self-governing organizations have often restricted membership by establishing several criteria for group membership, such as cultural affiliation, geographic location and residence, and the consent of existing members (Berkes et al. 1989; McCay 1980; Bromley 1990; Agrawal 2002; Mosimane and Aribeb 2008).

Furthermore, one cannot make sure that the exit option always has a positive impact on improving organizational performance even if it is easy for members to move to a better performing organization. According to Hirschman (1970), it is possible that those who are more sensitive to a decline in their organization leave the organization earlier than other members. The organization may lose a chance itself to find and correct its problems if the more quality-conscious members exit too quickly and gigantically to allow their organization to have enough time to react to it. As a result, free exit could increasingly widen performance gaps between organizations.

Both a closed membership policy and the potential negative effect of exit lead us to recognize the important role of the voice option as an alternative feedback mechanism. **In Chapter 3, I utilized qualitative comparative analysis (QCA) of self-governed fishery systems to understand how institutional and social-ecological conditions collectively determine the effectiveness of the voice option for controlling rule infractions**. Self-governing organizations make a set of rules for curbing the overexploitation of CPRs and the underinvestment into a shared infrastructure. However, members are often tempted to violate the rules because the benefits from rule infractions (i.e., private gains from cheating) are private and excludable while the costs of rule violations (i.e., resource degradation) are shared by others.

To sustain CPR systems against rule infractions, self-governing organizations have developed institutional arrangements that help make members' voice heard about who violated rules, what level of sanction is appropriate for the offender, and how to resolve conflicts related to rule infractions. In Chapter 3, I identify such voice-promoting institutions as Ostrom (1990)'s three design principles (DPs): DP 4 (monitoring), DP 5 (graduated sanctioning), and DP 6 (conflict-resolution mechanisms).

Besides the institutional conditions, resource mobility (ecological condition) and group size (social condition) are also able to affect transaction costs of the voice options for monitoring and enforcement. Compared to mobile resource units, stationary units can be governed with lower costs of information and transaction because they are more readily monitored (Schlager, Blomquist, and Tang 1994; Gutiérrez, Hilborn, and Defeo 2011; Agrawal 2001). Monitoring cheaters can also be less costly in small groups because they become more visible as group size decreases (e.g., Agrawal & Goyal, 2001; Boyd, Gintis, & Bowles, 2010; Esteban & Ray, 2001; Olson, 1965; Tucker, 2010).

Based on these institutional and social-ecological conditions, I conduct a qualitative comparative analysis of 30 self-governing fishing groups in South Korea to generate empirical hypotheses about what combinations of the conditions are likely to lead to successful functioning of the voice option.

1.4. Public Good Games: Exit

In Chapter 3, I use self-governed fishery systems as a testing ground to explore under what set of conditions the voice option can work effectively as social feedback mechanisms for self-controlling rule infractions. **Through agent-based modeling, Chapter 4 aims to examine under what set of socioeconomic conditions the exit option can have a positive or negative impact on collective action under the threat of free riding.**

To this end, I use public goods dilemmas as an example of collective action problems, and define the exit option as neither producing collective benefits nor consuming collective benefits produced by others (e.g., Hauert et al., 2007; Janssen, 2008; Orbell et al., 1984; Ye et al., 2011). Collective action for the provision of a local public good is critical to sustaining a SES. For instance, farmers must maintain shared irrigation canals collectively (i.e., regular repair works and desilting) in order to take irrigated water enough for crops. However, farmers are often tempted to free ride because those who do not contribute to maintaining the canals can benefit from the contributions of the others.

The difficulty of achieving a sufficient level of collective action has motivated many scholars across disciplines to study how to solve the free riding problems. It turns out that several factors can affect collective action, such as communication (Ostrom, Walker, and Gardner 1992; Janssen et al. 2010), altruistic punishment (Boyd et al. 2003; Sigmund et al. 2010), and group size (Esteban and Ray 2001; McCarthy, Sadoulet, and De Janvry 2001; Yang et al. 2013).

To explore how to overcome collective action problems, some studies are interested in effect of the exit from collective action on cooperation for the provision of local public goods. However, there is no consensus on effect of the exit option on cooperation. Some suggest that the exit option undermines cooperative behavior (Bland Platteu 1996, Fujita et al. 2000, Bardhan 2000) while others find that the exit option can have a positive effect on the evolution of cooperation (Hauert et al. 2007; Janssen 2008).

With the nature of the exit effect remaining elusive, the exit option becomes more available because economic opportunities outside of collective action arenas have been increasing due to sociotechnical changes and globalization. For example, an advanced technology for borehole drilling helps incentivize farmers to use privately-owned tubewells instead of shared irrigation canals requiring collective efforts for operation and maintenance.

These academic and real-world trends motivate me to investigate a set of socioeconomic conditions that may impact the effectiveness of the capacity to exit from collective action situations in enhancing levels of cooperation. A major economic condition of interest in this study is the exit payoff that directly influences individual decisions about whether to participate in collective action. In my simulation model, the exit payoff is assumed to be independent of others' choices and given exogenously to those who exit from collective action situations. In contrast, the payoffs for participants (e.g., defectors and cooperators) in collective action situations vary over time, depending on the fraction of cooperators.

In addition to the exit payoff, group interactions were considered as social factors that may also affect the effectiveness of the exit option in enhancing levels of cooperation. In response to a decline in participation in collective action (conversely, an increase in the number of exiters), more successful groups could be identified as either groups with more cooperators or groups with fewer exiters.

I assume that more successful groups take over other groups through cultural group selection based on the following two types of group interactions: the *More-Coop* group interaction defined as the social process through which a group with more cooperators is likely to take over another group with fewer cooperators; and the *Less-Exit* group interaction defined as the social process through which a group with fewer exiters is likely to take over another group with more exiters.

In Chapter 4, I calculate the long run average frequencies of cooperation under the *More-Coop* and *Less-Exit* group interactions, respectively. By comparing the long run results, I explore under what kind of group interaction the exit option has a positive or negative impact on cooperation.

1.5. Significance Statement

External shocks to SESs, such as climate change and globalization, have often made rapid and unexpected changes to the systems that have been stable for a long time. Unprecedented natural disasters cause serious damage to human-made infrastructures for managing CPRs and lead to a dramatic decrease in resource stock. Globalization has made more available the economic opportunities (e.g., non-farm income) that motivate individuals to leave their resource-dependent communities.

It is difficult to expect that these external shocks can contribute to mitigating the emergence of collective action problem from within SESs. Some human-subject experiments found that environmental variability and economic globalization are more prone to decrease levels of cooperation for maintaining and operating shared infrastructure (Anderies et al. 2013; Cárdenas et al. 2017). In the era of climate change and globalization, therefore, the role of social feedback mechanism becomes more critical to dealing with collective action problem.

This dissertation aims to explore under what conditions social feedback mechanisms can work properly to cope with internal stresses which are often identified as collective action problem within SESs. In the light of research on social feedback mechanism, this dissertation is of significance in the following five aspects.

1. **Analyzing different domains**: This dissertation analyzes three different domains of SESs: the coexistence of government-managed irrigation system and groundwater market (Chapter 2), self-governed fishery systems (Chapter 3), and public good games in self-governed systems (Chapter 4)
2. **Contextualizing internal stresses**: This dissertation contextualizes internal stresses in the three different domains above: bureaucratic shirking (Chapter 2) in government-managed irrigation systems, rule infractions (Chapter 3) in self-governed fishery systems, and free riding in public good games (Chapter 4).
3. **Specifying social feedback mechanisms**: This dissertation specifies social feedback mechanisms as the exit and voice options that individuals can choose to cope with internal stresses: both the exit and voice options in response to bureaucratic shirking (Chapter 2); the voice option in response to rule infraction (Chapter 3); and the exit option in response to free riding problem (Chapter 4)
4. **Exploring conditions**: This dissertation explores a variety of conditions under which social feedback mechanisms can contribute to enhancing the performances of SESs: irrigation bureau's reaction (Chapter 2); resource mobility, group size, and Ostrom's DPs (Chapter 3); and exit payoff and intergroup interaction (Chapter 4)
5. **Using multiple methods**: This dissertation shows the possibility that multiple methods, such as dynamic mathematical modeling (Chapter 2), qualitative comparative analysis (Chapter 3), and agent-based modeling (Chapter 4), can be used for the study on social feedback mechanisms.

CHAPTER 2

EXIT, VOICE, AND BUREAUCRATIC REACTION IN GOVERNMENT-MANAGED IRRIGATION SYSTEMS

2.1. Introduction

Government-managed irrigation systems command over 60% of the total irrigated area worldwide and thus stand to gain the most from enhanced irrigation performance (Burton 2010). The performances of these systems (i.e., physical condition and irrigation efficiency) to date, however, have been generally less than satisfying in many developing and less-developed countries (Suhardiman and Giordano 2014; Mukherji et al. 2009; Lam 1998). A great deal of policy efforts have been expended on the question of how irrigation services in these countries can be improved, resulting in transformation of many government-provided irrigation systems into either farmer-managed or privatized systems (Johnson III, Svendsn, and Gonzalez 2004; Molle, Mollinga, and Wester 2009). However, a closer look at their experience reveals that such institutional reforms can also be unsuccessful and subtly influenced by diverse contextual conditions. For example, irrigation management transfer from states to farmers often leads to bureaucratic resistance (Suhardiman and Giordano 2014), reinforcement of bureaucratic control over the irrigation districts (Molle, Mollinga, and Wester 2009), and underinvestment in maintenance (Vermillion et al. 2000). The switch to privatized irrigation systems can also fail in the absence of enabling physical, cultural, and institutional conditions that are conducive to water markets (Easter and Qiuqioing 2014). One of the main lessons from irrigation reforms over the past 50 years and the debates on them (Senanayake, Mukherji, and Giordano 2015) is that "there is a need for more research on combinations of institutions, rather than the performance of single institutions in presumed isolation." (Meinzen-Dick 2007, 15205)

To further explore the lesson about combinations of water institutions, this study addresses how the interplay of two different institutions affects the government-managed irrigation systems: participatory institutions and groundwater market institutions. The key structure of participatory institutions is that farmers pay irrigation service fees to government agency in exchange for not only water they receive, but also the right to assert their opinions or voice in determining operation and maintenance (O&M) needs (Bruns 2004; Groenfeldt and Svendsen 2000). Because water users' voice can enhance the democratic accountability and responsiveness of irrigation agencies in charge of the O&M, participatory institutions can be understood as a political supplement to government-managed systems. In comparison, groundwater market institutions work by giving farmers a substitute means to secure the services provided by public infrastructure, namely, private infrastructure. For example, increasing use of privately-owned tubewells has led to active informal groundwater markets at the local level in northern China and South Asia (Shah 2009; Wang et al. 2014). Farmers can thus buy irrigation services from the owners of tubewells in response to the decline in public infrastructure managed by government agencies. Economic literature on government failures has suggested that promoting competition between public and private entities will likely improve a given service which has been provided by a monopolistic state agency (Vining and Weimer 1990).

Blending the political and economic mechanisms to improve government-managed irrigation systems raises two key questions: how the combination of participatory and groundwater market institutions shapes farmers-agency interactions, and under what conditions the institutional combination help sustain government-managed irrigation systems. I address these questions by developing and analyzing a stylized mathematical model of the interactions between farmers and a government irrigation agency. The co-existence of groundwater market and participatory management gives farmers two basic options, *exit* and *voice*, which Hirschman (1970) proposed as the pressure mechanisms to improve the poor performance of organizations.

The exit option means that farmers stop paying irrigation service fees to government agency and instead buy water services from private infrastructure providers. It is obvious that exit to groundwater market generates a loss of revenue to government agency, which exacerbates as more farmers choose to exit. The voice option means that while still using agency-controlled irrigation in decline, farmers articulate their discontent with the delay or inefficiencies of the agency in charge of the O&M. Dissatisfied farmers can occupy the time of the agency's workforce and lead irrigation managers to cater to farmers' O&M needs for irrigation efficiency (i.e, physical infrastructure repair, rule development, better technology). To the extent that this is the case, voice can inflict direct management costs on poorly performing irrigation agencies.

Besides the two choices of farmers, the agency's reaction to them should be explored to advance our understanding of farmers-agency interactions shaped by the coexistence of participatory and groundwater market institutions. However, the "internal dynamics of hydrocracies" facing external challenges has been under-researched in water governance studies (Molle, Mollinga, and Wester 2009). Based on Hirschman (1970)'s idea on non-linear response of organizations to the monetary losses, agency's reactions are characterized in my model by two thresholds: a minimum threshold of the loss beyond which the agency starts putting effort into O&M (conversely, no effort before the minimum threshold); and a maximum threshold of the loss under which the agency keeps doing O&M activities (conversely, no effort after the maximum threshold). As the minimum threshold gets lower, the sensitivity of agency to exit and voice gets higher. As the maximum threshold gets higher, the durability of O&M activities against monetary losses gets higher.

Using a stylized model of farmers-agency interactions shaped by groundwater market and participatory institutions, I address the question of how the institutional combination affects the sustainability of government-managed irrigation systems in two stages. First, I explore the effects of the agency's reaction variations on long-term system behavior. I examine four types of government agencies varying with sensitivity (low and high) and durability (low and high). The model results suggest that changes in sensitivity and durability can generate regime shifts, i.e., critical transitions in the structure and function of systems (Polasky et al. 2011). Depending on the agency types, three different regimes (public, private, and mixed irrigation economy) expanded, shrunk, and disappeared.

Unlike the first analysis emphasizing the actions of the agency, my second analysis focuses particularly on the role of farmers who remain silent without exercising either ‘exit or ‘voice’ options. The silence option has been often pointed out as the missing element of Hirschman’s discussion on responses to decline in organizations (Gehlbach 2006). To capture those exercising neither ‘exit’ nor ‘voice’ options, several studies have incorporated ‘silence’ into a set of choices available to customers, members, and citizens (e.g., Barry, 1974; Clark et al., 2017; Laver, 1976; Warren, 2011). In line with those studies, my second analysis explicitly considers the silence option to examine how silent farmers affect long-term system behaviors with reference to the first analysis of the binary model where there are no silent farmers. I found that the silence option is a double-edged sword because it can impede a further improvement in public infrastructure, but in some cases, make a dramatic improvement in public infrastructure.

2.2. Model Structure

Improving government-managed irrigation systems depends not only on direct capital investment in new facilities, but also on human efforts into the O&M of existing infrastructures. Yet evidence of the water management problems has shown that ensuring prompt and adequate activities for the O&M is often a critical challenge to developing countries due to the lack of appropriate incentives to keep the existing systems in good condition. For instance, irrigation officials’ promotion and salary in Nepal are predominantly determined by the seniority system that has nothing to do with the O&M performance, such as effective delivery of water or agricultural productivity (Ostrom, Lam, and Lee 1994). In addition to the lack of individual incentive programs, the political tendency to maximize bureaucratic power (i.e., budget, staffs, and heavy equipment) can lead hydraulic bureaucracies to be less interested in quality management for aging infrastructures than quantitative increase in new infrastructures through construction projects (Molle, Mollinga, and Wester 2009).

Given the institutional and political situations creating the potential for bureaucratic shirking, the exit-voice model accounts for the role of voluntary interactions between farmers and irrigation agency in improving government-managed systems. A traditional way to discipline ill-behaving and shirking bureaucrats relies on the use of state apparatuses (i.e. higher authorities and court) that assume legitimate positions to punish them. Unlike the authoritative mechanisms, my model explores how two self-interested actors (farmers and irrigation agency) choose their strategies under the co-existence of groundwater market and participatory institutions, and how their interactions self-organize system behaviors in the long-term. Before describing the details of the model structure, I need to clarify that my aim is not to accurately model the dynamics of a particular government-managed irrigation system. Rather, I studied a stylized model to better understand the potential mechanism for regime shifts that provides us with lessons for the sustainable government-managed systems governed by diverse institutions observed across developing countries.

2.2.1. Human-Made Public Infrastructure Dynamics

In this model, public infrastructure is provided by a government irrigation agency and contributes to farmers' sustainable appropriation of surface water. Public infrastructure can be either hard or soft as a human-made medium of natural resources and resource exploitation (Anderies, Janssen, and Ostrom 2004; Anderies, Janssen, and Schlager 2016; Anderies 2015). For example, irrigation canals are hard human-made infrastructures that require investment (time and effort) via the agency to maintain their functionality (i.e., water delivery). Irrigation performance of government-managed systems is not only in relation to the condition of physical infrastructures, but also in conjunction with irrigation agency staffs' role in watering irrigated fields in response to social-ecological contexts (Suhardiman and Giordano 2014). A variety of rules regulating water distribution practices and physical infrastructure provision are soft human-made infrastructures. They can contribute to keeping irrigation bureaucrats from making unfair and arbitrary decisions about how to maintain and operate physical infrastructures.

I focus on hard human-made public infrastructure, such as canals, weir, and pipes, all of which requires proper and timely O&M activities for efficient delivery of irrigation water to farmers. I denote the quality of public infrastructure with q_{HM} (subscript HM for hard human-made). The dynamics of q_{HM} is described by

$$\frac{dq_{HM}}{dt} = M(R(\ldots)) - \delta q_{HM}, \qquad [1]$$

where $M(\cdot)$ is the maintenance function and δ is the infrastructure's depreciation rate. $M(\cdot)$ depends on the reaction function, $R(\ldots)$, which represents the effort level made by an irrigation agency to improve public infrastructure in response to farmers' exit and voice. Details of $R(\ldots)$ will be provided in the subsection 2.2.3.

It is easy to understand what the hard infrastructure quality is, since the quality is observable and measurable physical condition (e.g., broken weir and leaking pipe).

However, one can raise a question as to what it means by soft infrastructure quality. A conceivable way of understanding the "soft" quality is to examine a degree of congruence between rules and the contexts in which the rules come into play. Recent challenges to social-ecological systems (i.e., climate change and ageing infrastructure) may create farmers' additional demands, such as rule modification associated with water distribution and facility repair. To make rules better fitted with changing environments, such demands should be fed back into rule-making processes. If this is the case, bureaucratic tendency to adhere to routinized O&M procedures is nothing but a disservice to farmers. When a gap between rules and the social-ecological contexts in which they operate is widened due to the lack of efforts for more context-specific rules, one can say that soft human-made infrastructures deteriorate.

2.2.2. Farmers' Strategies: Exit, Voice, and Silence

There are N farmers in a village. They have three strategies in response to a decline in public infrastructure: 1) exit to private infrastructure in groundwater market; 2) voice to help improve public infrastructure through participatory institutions; and 3) silence to use public infrastructure without making their voice heard. The fraction of "farmers exercising the exit option" (*E*s) in this village is denoted by x, and the fraction of "framers exercising the voice option" (*V*s) by v. Because the population shares must always sum to unity, the fraction of "silent farmers" (*S*s) is represented by $s = (1 - x - v)$. To derive a simplified form of the exit payoff to each farmer, I assume that farmers hold the same acreage. Such egalitarian share of farmland allows us to ignore differential demands of groundwater among *E*s (groundwater users), i.e., every farmer needs a same amount of water. I also assume that the marginal cost of groundwater pumping increases. Therefore, the market-clearing price in the groundwater market goes up as more farmers demand their fixed individual allocation of water. The increase in groundwater market price leads to a decrease in the profits of *E*s. Hence, the payoff to the exit option is:

$$\pi_x = b \cdot e^{-\sigma(xN)}, \qquad [2]$$

where the parameter σ represents how signicantly the exit payoff varies with the number of *E*s (xN). For instance, when the number of *E*s increases, an *E* obtains less earnings in the groundwater market if the marginal cost of groundwater pumping goes up more sharply. If the marginal cost is constant so that the exit payoff is not affected by the number of *E*s $(\sigma = 0)$, then all *E*s can earn b $(= 2)$ which is the same as the maximum payoff to the voice option described below.

*V*s must pay a fixed irrigation service fee (p) to the agency and also bear the cost of voice (c_v), such as "time and money in the attempt to achieve changes in the policies and practices" (Hirschman 1970, 39). Because *V*s still use the public infrastructure, their benefit depends on the quality of public infrastructure (q_{HM}). In this model, public infrastructure quality (i.e., repaired canals and context-specific rules) is characterized as a public good. For instance, each of *V*s can obtain more earnings from higher irrigation efficiency (hard infrastructure) or more context-specific rules (soft infrastructure) no matter how many farmers in a village use the public infrastructures. Such a public-good characteristic of improved public infrastructures differs from rivalry – the more users, the less earnings – among private infrastructure users that characterizes groundwater markets. The payoff to the voice option is:

$$\pi_v = \mu \cdot q_{HM} - p - c_v, \qquad [3]$$

where $\mu \cdot q_{HM}$ is the benefit function representing that an individual beneift increases as enhanced public infrastructures (q_{HM}) can deliver more surface water. The public infrastructure quality, q_{HM}, is between 0 and 1. And μ is the factor that converts individual water consumption to economic benefit (i.e., income from cash crop). Unlike *V*s, *S*s do not exercise the voice option while still paying the fixed irrigation service fee (p) to the agency to use the public infrastructure. Because they do not bear the cost of voice (c_v), the payoff to the silence option is:

$$\pi_s = \mu \cdot q_{HM} - p \qquad [4]$$

A selection mechanism, which governs a farmer's decision on exit, voice, or silence, will be provided in the form of replicator dynamics in the section 2.2.4.

2.2.3. Reaction of Agency to Farmers' Strategies

The strategic reaction of a government irrigation agency to both exit- and voice-driven monetary losses is captured in the decision as to how much effort (e) the agency will put to improve public infrastructures. The effort I am interested in is not to plan and implement large-scale hydraulic projects (i.e., dam construction). But rather it is associated with ad hoc or fundamental solutions for day-to-day O&M activities, such as physical infrastructure repair, silt removal, and knowledge production of water accounting (Grafton et al. 2018). I propose the agency's effort patterns based on two characteristics that are widely found in economic organizations including public service providers: *sensitivity* defined as how quickly efforts are made to enhance the quality of goods and services in response to monetary losses; and *durability* defined as how durably the efforts are sustained in the face of increasing losses.

In many developing countries, irrigation agencies receive funds from the national treasury (more broadly, a central government), since the irrigation service fees collected from farmers are not sufficient to maintain the irrigation systems (Johnson III, Svendsn, and Gonzalez 2004; Meinzen-Dick 2014). Such maintenance funds from the national treasury may allow some room for a delayed reaction of the centrally-funded agency to a certain amount of monetary losses, thereby leaving public infrastructure deteriorating to some extent. However, the "latitude for deterioration" (Hirschman 1970, 5) owing to the deficit-covering mechanism cannot be unlimited. As monetary losses increase to a certain point at which a critical debate over government failures is provoked, the central government and the legislature will likely try to transfer irrigation management to farmers or business entities. Such an attempt (i.e., neoliberal reform) to seek alternative organizational forms is one of the most serious threats to risk-avoiding bureaucrats. Hence, the agency starts undertaking the O&M activities to improve public infrastructure when monetary losses trigger irrigation reforms aimed at weakening bureaucratic power. However, the efforts cannot continue to be made if monetary losses exceed a certain point beyond which financial burden is too heavy to sustain the government-managed irrigation system.

Such a reaction pattern, which is described in the context of public infrastructure, is a special case of the non-linear reaction function suggested by Hirschman (1970): (i) no effort into quality improvement is made for a small loss; (ii) the effort can be continued within a range of the mid-size loss; and (iii) no effort can be made again if the loss exceeds a certain large amount (i.e., bankruptcy and shutdown). Hirschman's reaction function is useful to capture sensitivity and durability because sensitivity is a reaction threshold between (i) and (ii), and durability between (ii) and (iii). My mathematical elaboration of the reaction function begins with identifying monetary losses caused by exit and voice. If a farmer exits public infrastructure, the agency experiences the revenue loss that is identical to the irrigation service fee (p). Thus, the maximum loss in revenue is pN when all farmers (N) in a village exercise the exit option. Unlike the exit option associated with revenue losses, the voice option inflicts direct management costs on the agency (i.e., the agency needs to deal with farmers' dissatisfaction). In general, the exit option can put more monetary pressure on the agency than the voice option. Hence, the maximum cost inflicted by voice can be θpN $(0 < \theta \leq 1)$ if all farmers in the village exercise the voice option. I assume that in proportion to a group size of Vs (v), the voice-driven cost decreases from the maximum cost. Finally, the monetary loss varying with population dynamics is $pNx + \theta pNv$.

Based on the monetary losses, one of the simplest ways to visualize two reaction thresholds (sensitivity and durability) is as a piecewise linear relationship between the monetary pressure and the agency's effort into the O&M:

$$R(L) = Effort = \begin{cases} 0, (L < L_{min}) \\ \dfrac{L - L_{min}}{L_{max} - L_{min}}, (L_{min} \le L \le L_{max}) \\ 0, (L > L_{max}), \end{cases} \quad [5]$$

where L is a loss index calculated by dividing the monetary loss, $pNx + \theta pNv$, by pN which is the maximum potential loss that occurs to the agency when all farmers use the private infrastructure. Hence, the loss index, $(= x + \theta v)$, represents the monetary loss which is measured relative to the maximum potential loss. For convenience, I shall call L monetary loss or pressure interchangeably instead of loss index. The parameter L_{min} is a minimum threshold of L at which the agency starts to put effort into the O&M. As L_{min} becomes smaller, the sensitivity of agency to exit and voice gets higher. The parameter L_{max} controls a maximum threshold of L beyond which no more effort can be made because the loss is too much to maintain the public infrastructures. As L_{max} becomes larger, the durability of agency to monetary losses gets higher. Between L_{min} and L_{max}, the effort level is assumed to be linearly increasing as monetary loss increases. Therefore, the maintenance function M in [1] can be defined as

$$\begin{aligned} M\big(R(\ldots)\big) &= \varepsilon R(L) \\ &= \varepsilon R(x + \theta v), \end{aligned} \quad [6]$$

where ε is the effectiveness of the O&M effort on public infrastructure quality.

2.2.4. Coupled Dynamics

The following differential equation is derived from [1] and [5] to represent the dynamics of public infrastructure:

$$\frac{dq_{HM}}{dt} = \varepsilon R(x + \theta v) - \delta q_{HM} \quad [7]$$

To capture the dynamics of strategic behaviors of the farmers, I use a replicator equation. Replicator dynamics describes human actors as possessing bounded rationality, which means that their behavior is "intendedly rational but only limitedly so" (Simon 1961, xxiv). A population of boundedly rational actors is not assumed to fully analyze the incentive structure, but rather to use only a limited set of information to replicate strategies with higher payoffs (Muneepeerakul and Anderies 2017). In my model, the information for a farmer to use to decide each period on exit, voice, or silence is other farmers' payoffs given their strategies. Following the formal structure of a replicator equation, the selection mechanism can be written as:

$$\frac{dx}{dt} = lx(\pi_x - \bar{\pi}), \quad [8]$$

$$\frac{dv}{dt} = lv(\pi_v - \bar{\pi}), \quad [9]$$

where x and v are the frequency at which the exit and voice options are being used, respectively. Accordingly, I may substitute $1 - x - v$ for the proportion of silent farmers (s). π_x and π_v are the payoffs to the exit and voice options, respectively. $\bar{\pi} = x\pi_x + v\pi_v + (1 - x - v)\pi_s$ is the average payoff in population as a whole, and l is the responsiveness of farmers to payoff difference.

2.3. Analysis I: Effects of Bureaucratic Reactions

In this section, I analyze a binary model in which all farmers actively use two available institutions (groundwater market and participatory institutions), i.e., choose either the exit option (using private infrastructures) or the voice option (putting pressure on the agency). It is obvious that when there are no silent farmers, the agency experiences more monetary loss at each time step than when there are inert, silent farmers. Hence, analyzing the binary model helps us better understand the details of how system dynamics are shaped when farmers push the agency towards more extreme conditions in terms of monetary loss. Because there are no silent farmers in the binary model, the proportion of farmers exercising the voice option is $v = 1 - x$. Accordingly, the average community-wide payoff is $\bar{\pi} = x\pi_x + (1 - x)\pi_v$. Therefore, equation [9] is the same as equation [8]. As a result, government-managed irrigation systems are captured by the two-dimensional dynamical system where population dynamics (equation [8]) is coupled with hard human-made infrastructure dynamics (equation [7]). Here, my analytical focus is particularly on how the agency's reactions to the monetary loss (i.e., sensitivity and durability) affect system dynamics. Such binary model analyses provide useful information (e.g., steady states) for my further analysis of a trinary model consisting of exit, voice, and silence. By comparing the results of the two different models, I can investigate how silent farmers can play an important role in changing steady states. The analysis of the model with three options is provided in the next section.

2.3.1. Agency Types: Sensitivity and Durability

In my model, variations in the agency's behavior are characterized by two reaction thresholds (sensitivity and durability). Such thresholds affect public infrastructure improvements through which farmers' relative payoffs associated exit and voice are determined and thus result in population dynamics. I classified four types of agency to investigate how different levels of sensitivity and durability lead to different steady states represented by two state variables, public infrastructure quality (q_{HM}) and Es-to-population ratio (x). Fig. 2.1 shows each agency's reaction function that relates O&M effort level (e) to monetary loss (L) caused by farmers' exit and voice.

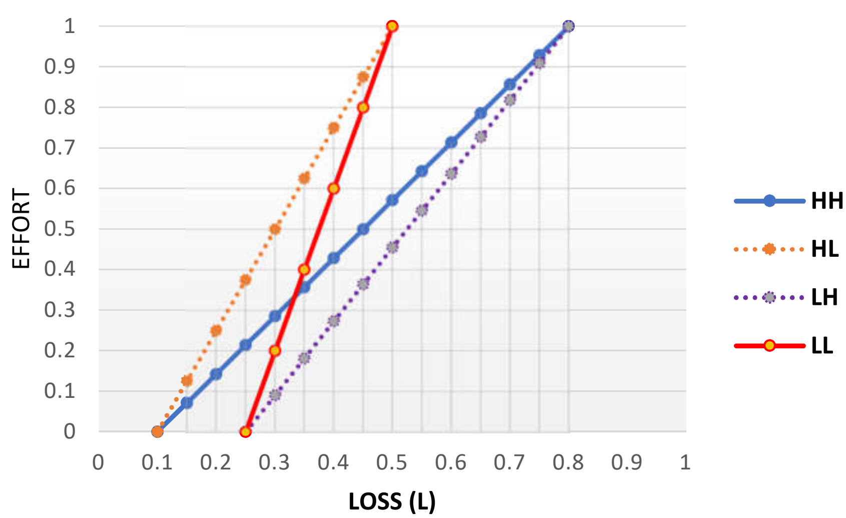

Figure 2.1. Four types of agency. HH (High sensitivity, High durability), LH (Low sensitivity, and High durability), HL (High sensitivity, Low durability), and LL (Low sensitivity, Low durability). Using two threshold parameters, L_{min} and L_{max}, in reaction function (See equation (4)), I characterize low sensitivity as $L_{min} = 0.25$, high sensitivity as $L_{min} = 0.1$, low durability as $L_{max} = 0.5$, high durability as $L_{max} = 0.8$.

Table 2.1. Variables and parameters

Symbol	Definition	Default value
Variables		
x	Fraction of farmers using (exiting to) groundwater	
q_{HM}	Quality of the human-made public infrastructure	
L	Loss index	
Parameters		
N	Number of farmers	100
σ	Effect of the number of groundwater users (*E*s) on their payoff	0.0125
b	Maximum payoff to the exit option (when $\sigma = 0$)	2.0
μ	Conversion factor from public infrastructure quality to a farmer's income	2.25
p	Fixed fee to government irrigation agency	0.2
c_v	Cost of voice	0.05
L_{min}	Minimum threshold of L at which government irrigation agency starts putting effort into the O&M.	varies with agency types
L_{max}	Maximum threshold of L beyond which government irrigation agency quits putting effort into the O&M	varies with agency types
ε	O&M effectiveness of government agency	0.7
δ	Depreciation rate of public infrastructure	0.1
θ	Voice-driven loss relative to exit-driven loss	0.2

Note that the numbers given to sensitivity and durability (Fig. 2.1) are not based on empirical data, but rather for convenience of cross-agency-type analyses that aim to explore the effects of sensitivity and durability on long-term system behavior. For example, I can investigate the effect of sensitivity by comparing the high-sensitivity agencies with the low-sensitivity agencies, *ceteris paribus* (i.e., HH vs. LH, and HL vs. LL). It is also possible to understand the effect of durability by comparing the high-durability agencies with the low-durability agencies, *ceteris paribus* (i.e., HH vs. HL, and LH vs. LL). Table 2.1 summarizes a set of variables and parameters used in the model analysis.

2.3.2. Cross-Agency-Type Analysis

Fig. 2.2 is a phase plane representation of both public infrastructure quality (y axis) and *E*s-to-population ratio (x axis) in the system. Three possible governance regimes emerge from the system as the values of sensitivity and durability are changed that characterize types of irrigation agency. These regimes are defined by the set of all initial states that converge to a particular long-run configuration. The first regime is represented by the blue region in the top two panels in Fig. 2.2 which converges to the public irrigation economy (*PUBLIC-Vs*) in which all farmers exercise the voice option and use the fully functioning government-managed infrastructure. The second regime is the red colored region which converges to the private irrigation economy (*PRIVATE-Es*) in which all farmers use the private infrastructure instead of the collapsing public infrastructure. Finally, the purple colored region converges to the mixed irrigation economy (*MIXED-EVs*) in which some farmers exit to private infrastructure while others use the public infrastructure with the voice option exercised. The proportion of *Es* and *Vs* is determined by the replicator equation [8]. I investigate the characteristics of these regimes in more detail in the following paragraphs.

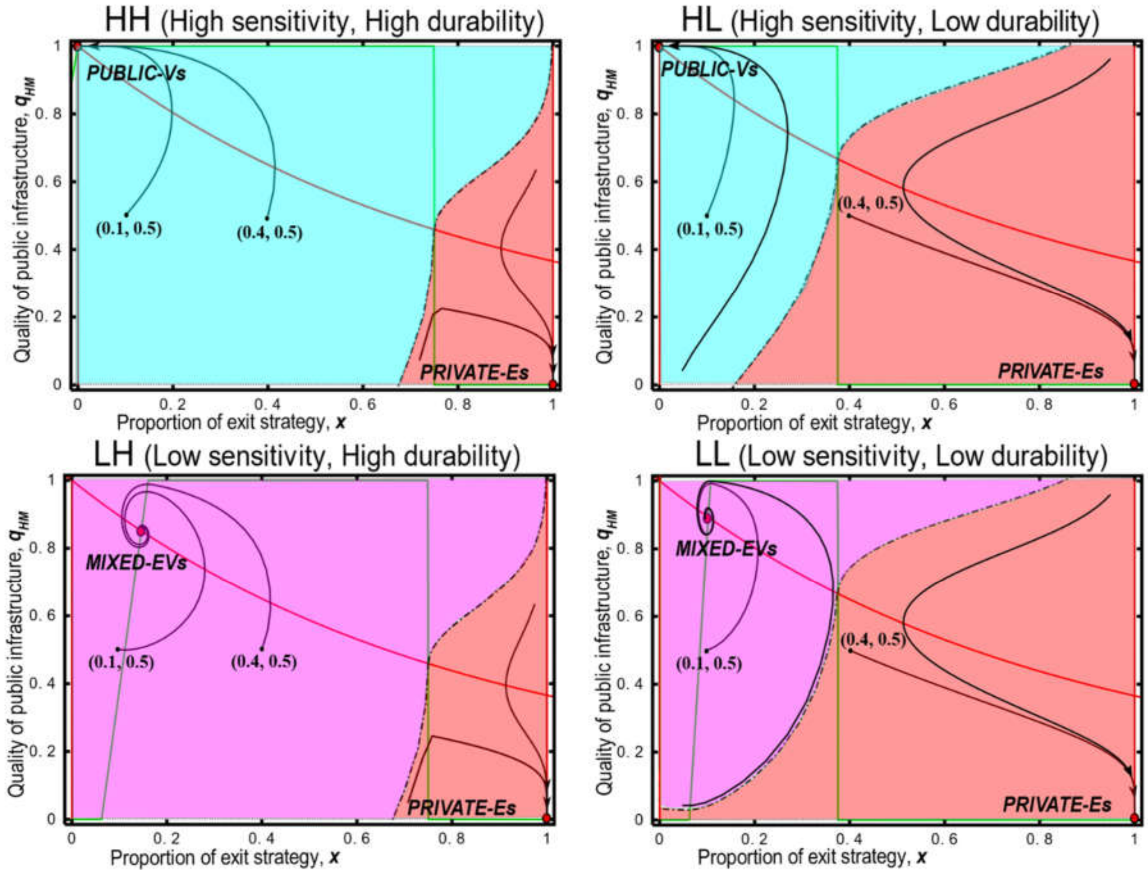

Figure 2.2. Effects of sensitivity and durability on long-term system behavior. Four types of irrigation agency are represented by HH, HL, LH, and LL. The x and y axes show the fraction of farmers who exercise the exit option (x), and the quality of public infrastructure (q_{HM}), respectively. Red and green lines represent x and q_{HM} nullclines, respectively. Arrows represent the flows of dynamics from particular initial states. Three possible irrigation regimes are *PUBLIC-Vs* (blue area), *PRIVATE-Es* (red area), and *MIXED-EVs* (purple area). At *PUBLIC-Vs*, all farmers exercise the voice option and the government-managed public infrastructure is fully functioning. At *PRIVATE-Es*, all farmers exit to privately-owned tubewells and the public infrastructure collapses. At *MIXED-EVs*, some farmers exit to the private tubewells and others use the fairly-functioning public infrastructure with the voice option exercised.

The role of agency sensitivity: Improving public infrastructures

A closer look at the *PUBLIC-Vs* and *MIXED-EVs* regimes emerging from four types of agency reveals that the sensitivity of agency to exit and voice plays a critical role in achieving fully-functioning public infrastructure. Two high-sensitivity agencies (HH and HL) can fulfill the maximum quality of public infrastructure ($q_{HM} = 1$) while two low-sensitivity agencies (LH and LL) cannot ($q_{HM} < 1$). To understand the mechanism underlying the role of sensitivity, I pick an initial condition $(x, q_{HM}) = (0.1, 0.5)$ that is one of the examples from which no system converge to *PRIVATE-Es* regardless of agency types (see Fig. 2.2). At the outset, the payoff from private infrastructure is greater than that from public infrastructure. Such a payoff difference leads more farmers to change their strategy towards the exit option, thereby resulting in two major impacts to farmers and the agency.

The behavioral change towards the exit option, on the one hand, makes exit payoff smaller as the groundwater market price goes up. This will likely keep farmers from exiting to private infrastructure. Another impact of the switch to the exit option is that the agency experiences more losses because an *E* takes away more money from the agency than a *V* (recall $p > \theta p$ in Subsection 2.2.3). In the middle of the increase in loss, it is high sensitivity that contributes to improving public infrastructure very rapidly. This is because, compared to the delayed response (low sensitivity), the quick response will likely make it for the agency to put more effort in the face of a given size of loss. Once public infrastructure is improved quickly and sufficiently to make no difference in payoffs from the exit and voice options, population dynamics is reversed in a sense that, unlike the early stage, the *E*s-to-population ratio starts to decrease and finally goes to zero (conversely, *V*s-to-population ratio increases). This is because despite the reversal of population dynamics, monetary pressure is maintained enough to further improve public infrastructure that determines voice payoff. Hence, two highly sensitive agencies can achieve the fully-functioning infrastructure and sustain it at *PUBLIC-Vs* in the long-run.

Public infrastructures managed by low-sensitivity agencies (LH and LL), however, deteriorate immediately after being improved to almost its fully functioning level. Public infrastructure quality, then, is maintained at some level between 0.8 and 1.0 in the long term. Such a deterioration occurring to LL- and LH-managed infrastructures is explained through the following mechanism. Once public infrastructure is almost fully recovered in the early stage through exit-driven pressure on the agency, farmers start to keep the exit option at bay because they are better off by using the improved public infrastructure. This indicates that the reversal of population dynamics (*E*s-to-population ratio decreases and *V*s-to-population ratio increases) also occurs to the system managed by low-sensitivity agencies.

However, unlike the systems managed by high-sensitivity agencies, the reversed population dynamics has a negative impact on public infrastructure improvements. This is because the decline in exit ratio reduces monetary pressure on the low-sensitivity agencies so that the agencies input less or no effort into public infrastructure improvements. The insufficient level of effort leads to a decline in public infrastructure, and thus cause slightly more farmers to exit to private infrastructure. Like the very first stage of system dynamics, the exit-driven pressure again leads the agencies to put sufficient effort in public infrastructure improvements. The processes I describe above, then, are repeated until the public infrastructure is recovered again up to the quality level (0.8~1.0) which makes no difference between exit and voice payoff. Because farmers have no incentive to change their strategy, the system eventually becomes stable at *MIXED-EVs*.

The role of agency durability: Enhancing resilience

As discussed above, the level of sensitivity affects whether or not public infrastructure can fully function in the long term. If an agency is highly sensitive to exit and voice, then the system can achieve fully-functioning public infrastructures; otherwise, public infrastructure quality can maintain under the fully-functioning level. As a result, I can see from Fig. 2.2 that different combinations of regimes emerge from the irrigation systems: a regime combination (*PUBLIC-Vs*, *PRIVATE-Es*) in the system managed by high-sensitivity agencies, and the other combination (*MIXED-EVs*, *PRIVATE-Es*) by low-sensitivity agencies. This indicates that the change of sensitivity affects the potential for regime shifts. For instance, a regime is shifted from *MIXED-EVs* to *PUBLIC-Vs* as the sensitivity gets higher. Conversely, the change of sensitivity from high to low leads to a regime shift from *PUBLIC-Vs* to *MIXED-EVs*.

Compared to the role of sensitivity in shifting regimes, durability affects how resilient public infrastructures are to an external shock. Fig. 2.2 shows that in the system managed by the low-durability agencies (HL and LL), *PUBLIC-Vs* and *MIXED-EVs* lose resilience (its basin of attraction shrinks) and *PRIVATE-Es* basin expands: compared to HH in Fig. 2.2, HL has smaller blue area that leads the system to *PUBLIC-Vs*; compared to LH, LL has smaller purple area that leads the system to *MIXED-EVs*; and the low-durability agencies (HL and LL) have larger red area that lead the systems to *PRIVAVE-Es* than the high-durability agencies (HH and LH). Such a loss of resilience suggests that public infrastructures managed by the low-durability agencies are more prone to collapse than those managed by the high-durability agencies even when they are all exposed to a same size of external shock. Conversely, high durability makes *PRIVATE-Es* basin shrunken, thereby increasing the potential for public infrastructure improvements. These results demonstrate that the size of shock, which a system can maintain its public infrastructure, is smaller as the agency's durability gets lower.

To understand how low durability creates narrower paths toward public infrastructure sustainability, I select a point $(x, q_{HM}) = (0.4, 0.5)$ to which a system is perturbed from a stable state (*PUBLIC-Vs* or *MIXED-EVs*). For instance, a typhoon could cause serious damage to public infrastructures critical to delivering surface water. The typhoon news itself could also be an exogenous, social factor that leads several farmers who are concerned about the damage to physical infrastructure to exit to groundwater markets. Faced with those external shocks to physical infrastructures and human decisions, the system managed by HH is capable of going back to *PUBLIC-Vs* at which public infrastructures are fully functioning. Given the same shock, however, the system managed by HL is not able to achieve *PUBLIC-Vs*. Similarly, the LH-managed system can still achieve *MIXED-EVs* at which public infrastructures fairly functioning while the LL-managed system experiences a collapse of public infrastructures. These findings suggest that a system's resilience to the shock relies on durability rather than sensitivity.

The reason that resilience depends on durability is found through comparison between the monetary loss at $(x, q_{HM}) = (0.4, 0.5)$ and the agency's maximum endurable loss. At $(x, q_{HM}) = (0.4, 0.5)$ the low-durability agencies (HL and LL) experience the loss (approximately 0.6) beyond the maximum loss that they can endure to improve public infrastructure; the high-durability agencies (HH and LH) are able to improve public infrastructure in response to the initial loss which is less than the maximum endurable loss. Hence, public infrastructures managed by the low-durability agencies continue to become poorer gradually if no support is given to them, and thus more farmers keep using private infrastructures. As a result, actual monetary loss keeps too greater over time for the low-durability agencies to have a chance to improve public infrastructure.

2.4. Analysis II: Effects of Silent Farmers

In Analysis I, I investigated how system dynamics are shaped with the absence of silent farmers (*S*s). I observed that three different regimes of the binary model expand, shrink, and disappear, depending on different patterns of agency's reactions to exit and voice. In this section, I analyze how system dynamics are changed with the presence of *S*s. The initial proportion of *S*s is set to be very low ($s_0 = 0.1$) to explore how such a small proportion of *S*s can make a dramatic change in system dynamics. Note that in this section I deal with three-dimensional dynamical systems consisting of hard human-made infrastructure dynamics (equation [7]) and two population dynamics (equation [8] and [9]). Hence, if initial values of three state variables, including x, q_{HM}, and v, are given to the system, 3-D trajectories will be shown in a space of the three variables (i.e., x, q_{HM}, and v can be shown on x, y, and z axes, respectively). To make it easy to compare the results of Analysis I and II, I projected the 3-D trajectories onto the same x-q_{HM} plane as in Analysis I. The trajectories shown in Fig. 2.3 below are those projected ones.

2.4.1. The Cost of Silence

In this subsection, I compare stable equilibria of the current trinary model with those of the previous binary model to identify how the silence option for farmers to avoid bearing the individual cost of voice (c_v) can impede public infrastructure improvement. It is the existence of the silence option that draws a line between the binary and the trinary models. Hence, differences in long-run results of the two dynamic models can be explained by the silence option. Fig. 2.3 shows that no matter what type of agency manages public infrastructure, there exist two stable equilibria in the current trinary model: *MIXED-ESs* and *PRIVATE-Es* (see two blue dots in each panel of Fig. 2.3). The *MIXED-ESs* represents the mixed irrigation economy in which some farmers exit to private infrastructure while all the remaining farmers still use the public infrastructure without exercising the voice option. Recall that instead of *MIXED-ESs*, the previous binary model has either *PUBLIC-Vs* or *MIXED-EVs* depending on agency types (see a red dot in each panel of Fig. 2.3). Black solid lines demonstrate the trajectories starting from some initial states of x and q_{HM} which converge to *MIXED-ESs* (blue dots) in the current trinary model but converged to *PUBLIC-Vs* or *MIXED-EVs* (red dots) in the binary model.

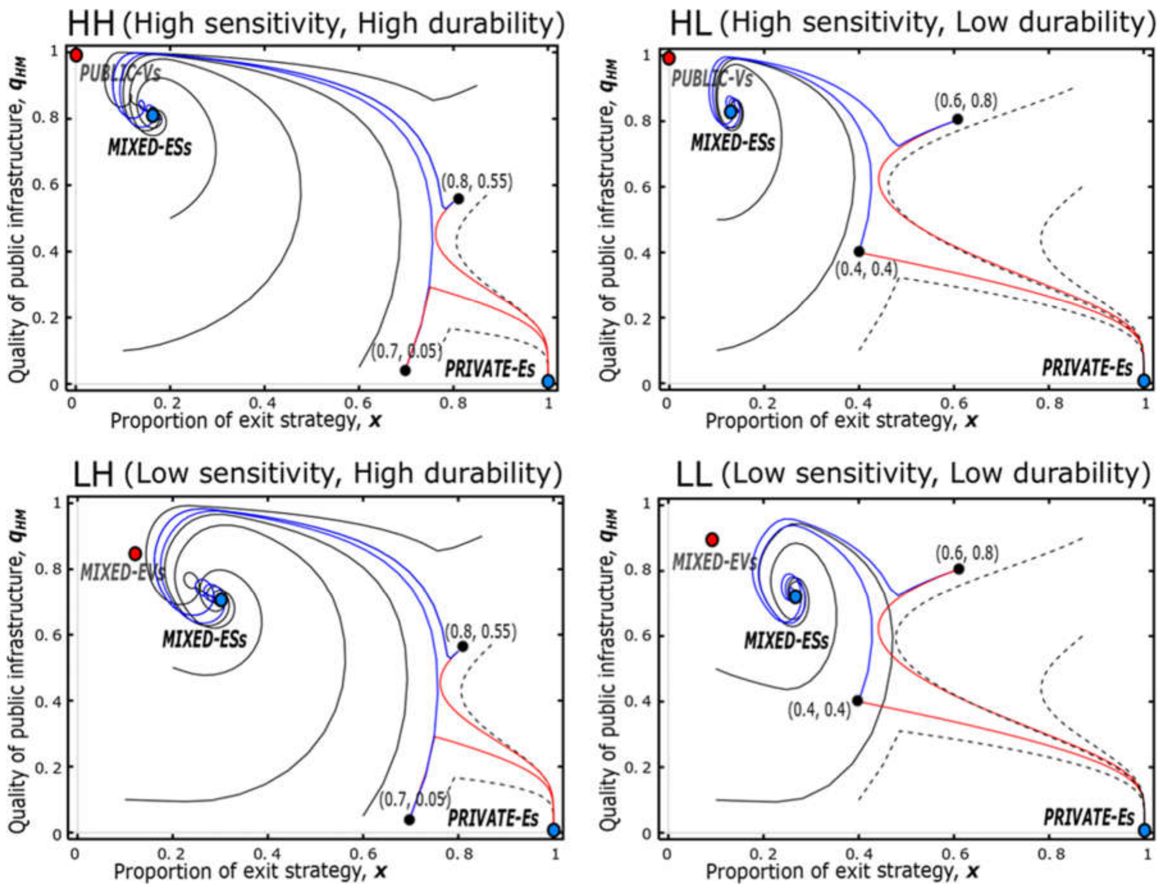

Figure 2.3. Effects of silent farmers on system dynamics in a trinary model. In each panel, the initial proportion of silent farmers is set to be 0.1 ($s_0 = 0.1$). Red dots (*PUBLIC-Vs/MIXED-EVs*) are long-term equilibria other than *PRIVATE-Es* in the binary model where all farmers exercise either 'exit' or 'voice' options. Blue dots (*MIXED-ESs/PRIVATE-Es*) are long-term equilibria in the current trinary model where all farmers exercise 'exit', 'voice', or 'silence' options. In the trinary model, *MIXED-ESs* (upper left blue dots) is achieved instead of *PUBLIC-Vs*/*MIXED-EVs* (red dots). This indicates that silent farmers impede a further improvement in public infrastructure. Black solid lines represent the trajectories originating in some initial states which converged to red dots in the binary model but converge to *MIXED-ESs* in the trinary model. In contrast, silent farmers can make a dramatic improvement in public infrastructure. For instance, black dots are examples of the initial states which converged to *PRIVATE-Es* (red trajectories) in the binary model but converge to *MIXED-ESs* (blue trajectories) in the trinary model. Black dashed lines show the trajectories heading to *PRIVATE-Es* in both models.

Comparing the trinary model to the binary model, I can recognize that even the small proportion of silent farmers ($s_0 = 0.1$) can move a stable equilibrium from

PUBLIC-Vs/*MIXED-EVs* (red dots) to *MIXED-ESs* (blue dots). Such movements indicate that in the long run, public infrastructure quality is maintained at lower levels in the presence of silent farmers (*S*s) than in their absence. This is mainly because the silence option is always more lucrative than the voice option (see equation [3] and [4]) so that farmers prefer to become silent rather than to bring effective pressures on the agency toward public infrastructure improvement at their own cost of voice. As the proportion of *V*s gets smaller over time, the impetus for public infrastructure improvement depends more heavily on the exit option. Yet, farmers who exit to private infrastructure cannot go it alone; instead, an adequate number of farmers exercising the voice option are needed to generate enough momentum to improve public infrastructure up to the quality level achieved in the absence of *S*s. However, the proportion of *V*s becomes smaller over time, and ultimately, remains zero in the long run. Meanwhile, the proportion of *S*s becomes greater so that all farmers are divided into exit group and silence group at *MIXED-ESs* where private and public infrastructures coexist.

Such a between-model analysis demonstrates that public infrastructure could have been further improved if *S*s had not been in the system. In the trinary model, individual farmers are likely to remain silent to not bear the cost of the voice option. The aggregate outcome of the individual decisions turns out to be a less improved public infrastructure in comparison to the binary model. Hence, the between-model analysis allows us to interpret the relatively lower quality of public infrastructure as the cost of silence. Furthermore, a close look at the systems managed by four types of agency in the trinary model helps us to find that the cost of silence differs across those systems in terms of public infrastructure quality. Compared to the bottom two panels (low-sensitivity agencies) in Fig. 2.3, *MIXED-ESs* is located higher in the top two panels (high-sensitivity agencies). This shows that the systems managed by high-sensitivity agencies (HH and HL) can achieve better functioning public infrastructures in the long run than those managed by low-sensitivity agencies (LH and LL). This finding is consistent with the role of sensitivity I analyzed in the binary model (see Subsection 2.3.2.1). The basic mechanism for making the difference to public infrastructure is that high-sensitivity agencies can keep putting effort into the O&M in response to small monetary losses at which low-sensitivity agencies make less or no O&M effort.

2.4.2. The Benefit of Silence

Silent farmers (*S*s) bear no cost of the voice option that brings effective pressures on the agency toward public infrastructure improvement. Hence, one can say that *S*s contribute nothing to improving public infrastructure and are thus free riders who causes a loss of momentum for further improvements in public infrastructure. The framing of *S*s as free riders makes sense when I consider my assumption of irrigation agencies. In this study, I did not assume that government agencies always fulfill their responsibilities by themselves to manage public infrastructure sustainably. Instead of such ideal types of public entities, the agencies were assumed to be a strategic counterpart playing an infrastructure management game with farmers. More specifically, it was assumed that the agencies start to put effort into O&M when farmers inflict a certain amount of monetary loss (L_{min} in equation [5] and Fig. 2.1) on the agencies. Because the monetary loss is the aggregate outcome of exit and voice, *S*s could be viewed as free riders who bring about the system's rapid loss of the momentum for improving public infrastructure.

However, the silence option does not always impede improvements in public infrastructure. Rather, regardless of agency types, the silence option can play a decisive role in enhancing public infrastructure quality considerably from zero to 0.7-0.8 in the long run. Examples of the dramatic shift are shown in Fig 3, given that the initial proportion of *S*s is 0.1 ($s_0 = 0.1$). Two black dots in each panel are the examples of initial states which converged to *PRIVATE-Es* in the binary model (i.e., the absence of the silence option) but converge to *MIXED-ESs* in the current trinary model (i.e., $s_0 = 0.1$). Red and blue lines illustrate the trajectories moving toward *PRIVATE-Es* in the binary model and *MIXED-ESs* in the current trinary model, respectively. One reason for the significant improvement in public infrastructure is that *S*s can reduce the risk that monetary loss is too excessive for the agency to put enough effort into O&M.

I assumed that the agencies are not able to keep doing O&M activities if monetary loss becomes larger than the maximum endurable loss (L_{max} in equation [5] and Fig. 2.1). In the trinary model, *S*s who inflict no monetary loss on the agency play a key role in making monetary loss lower than the maximum, thereby helping the agency to keep maintaining public infrastructure. However, there are no *S*s in the binary model, i.e., all farmers exercise either the exit or voice option. The lack of *S*s is likely to lead monetary losses to be greater than the maximum beyond which the agency makes no O&M effort. Note that the positive effect of silence on public infrastructure improvements is not observed at every initial state in the current trinary model. For instance, black dashed lines illustrate examples of the trajectories heading to *PRIVATE-Es* (public infrastructure collapse) in both the binary model and the current trinary model.

It is challenging to present some general conditions (if any) under which the silence option brings about the non-trivial shifts in the long-term equilibrium from *PRIVATE-Es* to *MIXED-ESs*. This is because I focused solely on a small initial proportion of *S*s ($s_0 = 0.1$) to explore how such a small change in demographics leads to a substantial change in the long-term equilibrium. Despite the lack of through investigations of all possible proportion of *S*s, my qualitative analysis of the trinary model provides the basis for a convincing explanation of the relationships of silence with exit and voice. First, silence can contribute to widening a range of the exit effect, which is defined the effect of exit on increasing the aggregate monetary pressure to the extent that the agency continues to put enough effort into public infrastructure management. Silent farmers put no monetary pressure on the agency, thereby keeping the exit effect from disappearing. Blue (presence of silence) and red (absence of silence) trajectories demonstrate the role of silence in making the exit effect at play to shift the long-term equilibrium from *PRIVATE-Es* to *MIXED-ESs*.

Second, a comparison of the blue and red trajectories also shows the relationships between silence and voice. In the binary model, all of those who do not exit to private infrastructure are alert farmers in the sense that all the not-exit farmers exercise the voice option. However, the trinary model allows for the possibility that alert and inert farmers can coexist, i.e., all the non-exit farmers either voice actively or stay silently. I found that the initial states (black dots), which converged to *PRIVATE-Es* in the binary model (red trajectories), converge to *MIXED-ESs* in the trinary model (blue trajectories). This suggests that a mixture of voice and silence could partially enlarge the *MIXED-ESs* regime while making the *PRIVATE-Es* regime shrink. When we recollect that participatory institutions enabling the voice option aim to enhance the democratic responsiveness of irrigation agencies, my finding is in line with a seemingly contradictory wisdom suggested by Hirschman and other political scientists (e.g., Almond and Sidney, 1965; Dahl, 1961): a "mixture of alert and inert citizens, or even an alteration of involvement and withdrawal, may actually serve democracy better that either total, permanent activism or total apathy" (Hirschman 1970, 32). In a nutshell, the relations between silence and system performance are more complex than had once been thought. Silence cannot be equivalent to a free-riding behavior harmful to public welfare and is not always bad for system performance if institutions facilitating exit and voice are well arranged.

2.5. Conclusion

A growing body of literature emphasizing that no institutional panacea exists for successful resource governance has highlighted the need to understand why we need to protect institutional diversity (Ostrom 2012). As institutional diversity has been made central in social-ecological systems (SESs) research, a group of studies have provided rich knowledge on how to improve system performance (i.e., income and infrastructure functionality) of a particular type of resource governance. For instance, Ostrom and her colleagues have been interested in self-governance of common-pool resources, and thus explored how to overcome collective action problems (i.e., resource overuse and infrastructure underinvestment) and how to make systems more robust (or resilient) to environmental variability (Ostrom 1990; Anderies et al. 2013; Yu et al. 2015, 2016; Cárdenas et al. 2017). Another group of studies have enriched our understanding of the need for institutional diversity through comparative analyses of multiple SESs managed by different governance modes. For example, several empirical studies compared the performance of irrigation systems managed by farmers themselves and a government agency, respectively (Ostrom, Lam, and Lee 1994; Joshi et al. 2000). Both groups of studies help us better understand how a single institution (i.e., government, market, and self-governance) governs natural resources and what problems are found in the institution.

However, little study has been done to investigate how a blending of different institutions in a single SES shapes the long-term dynamics of the system. To fill the gap left by studies on institutional diversity, I used a dynamic mathematical model in which different institutions coexist in an irrigation system: government agency in charge of the O&M of public infrastructures (i.e., shared canals and water distribution rules); groundwater markets where private infrastructure providers sell groundwater to farmers; participatory institutions through which farmers pay irrigation service fees to government agency in exchange of the right to input O&M needs into the agency. I identified three options (exit, voice, and silence) which are made available to farmers by the combination of groundwater market and participatory institutions. Both exit and voice options conceptualized by Hirschman (1970) can put monetary pressure on the agency. The exit to private infrastructure providers reduces the agency's revenue collected from irrigation service fees paid by farmers. The voice option can inflict direct management costs on the agency. The silence option, which is another available option to non-exit farmers, does not inflict the direct management costs on the agency. To capture a typical response of irrigation bureau to the monetary pressure of exit and voice, I used a simple version of Hirschman's non-linear reaction function characterized as sensitivity and durability: sensitivity defined as how quickly the agency starts to put effort in the O&M; and durability defined as how persistently the agency makes efforts to maintain infrastructure in the face of an increasing monetary loss.

Using a binary model in Analysis I, I examined how the system is dynamically shaped given that all farmers exercise either exit or voice options, i.e., the agency is exposed to more monetary loss due to the absence of silent farmers who remain in the system regardless of performance. I found that three irrigation regimes (*PUBLIC-Vs*, *PRIVATE-Es*, and *MIXED-EVs*) expand, shrink, and disappear as the two reaction characteristics (sensitivity and durability) are varied. Based on the regime shifts, I observed that high sensitivity is critical to improving public infrastructure and that high durability is a key to enhancing resilience of public infrastructures to an external shock. Using a trinary model (including silence) in Analysis II, I investigated how the silence option impacts long-term system behaviors with reference to the results of the binary model. Unlike the binary model with three irrigation regimes, two regimes (*PRIVATE-Es* and *MIXED-ESs*) emerge from the trinary model, i.e., *PUBLIC-Vs* is absent. My between-model analysis indicates that silence is a double-edged sword in terms of public infrastructure improvements. On the one hand, silent farmers could cause a loss of momentum for further improvements in public infrastructure. This is the cost of silence. But on the other hand, they could make a dramatic improvement in public infrastructure possible at some initial states (black dots in Fig. 2.3). This is the benefit of silence.

These findings provide valuable insights into irrigation reforms aimed at improving public infrastructure. With public infrastructure exposed to a competition with private infrastructure, policy makers may also want to further boost the pressure of voice on the LL agency that is in most urgent need of discipline by farmers. A lesson from my model analysis is that such a voice-friendly reform should be undertaken prudently. The cost of silence (limited improvements in public infrastructure) could be set off by the reform that will likely increase voice-driven monetary pressure to lead the agency to put more effort into O&M. However, public infrastructure will collapse if the voice-friendly reform is so strong that the aggregate monetary pressure of exit and voice on the agency is greater than the maximum endurable. Such negative returns to voice are likely to occur in a village where there are already a considerable number of farmers using private infrastructure. This is because the agency is initially exposed to a great deal of monetary loss due to the private infrastructure users. This line of reasoning suggests that a voice-friendly reform aimed at using the potential of voice could end in failure, paradoxically highlighting the role of silence in reducing the aggregate pressure for the agency to maintain persistent O&M activities.

Finally, I suggest some direction for further studies. I found that one of the long-term equilibria in the trinary model is *MIXED-ESs* where there are only exiting and silent farmers – no farmers exercising the voice option. Such a limited diversity of population at the steady state resulted mainly from the payoff difference between silence and voice. The silence payoff is always greater than the voice payoff because silent farmers do not bear the cost of the voice option. However, if social rewards (e.g. reputation) from exercising the voice option are added to the voice payoff function, there could be several famers who exercise the voice option in the long run instead of staying silent. If so, long-term equilibria would be characterized as a population mixture of exit, voice, and silence. Lastly, my analysis of the trinary model was based particularly on a small initial portion of silent farmers. Using a more advanced analytical skill, another future study may investigate long-term system behaviors at all possible initial proportions of silent farmers. Such a thorough investigation would help go beyond the current partial analysis to identify some general conditions under which silence plays a positive or negative role in improving public infrastructure.

CHAPTER 3

RESOURCE MOBILITY, GROUP SIZE, AND VOICE-PROMOTING INSTITUTIONS IN SELF-GOVERNED FISHERY SYSTEMS[*]

3.1. Introduction

Common-pool resources (CPRs) are often held by an identifiable group of users who have traditionally self-governed the resources for their livelihoods. Under the communal property, self-governing organizations have restricted membership on the basis of cultural affiliation, geographic location and residence, and the consent of existing members (Berkes et al. 1989; McCay 1980; Bromley 1990; Agrawal 2002; Mosimane and Aribeb 2008). The criteria for group membership (boundary rules *sensu* Ostrom) may contribute to the sustainability of CPRs by increasing the stability of group size and the predictability of members' behavior. But on the other hand, such a closed membership policy can make it difficult (if not impossible) for resource users to switch membership between organizations. The possibility of limiting individual mobility poses an interesting problem to CPR management because the availability of an option to choose a better performing organization has been recognized as a key mechanism that helps maintain and improve organizational performance (Hirschman 1970). This option,

[*] This chapter is based on the following paper: Shin, H.C., D.J. Yu, S. Park, J.M. Anderies, J.K. Abbott, M.A. Janssen and T.K. Ahn. 2020. How do resource mobility and group size affect institutional arrangements for rule enforcement? A qualitative comparative analysis of fishing groups in South Korea. *Ecological Economics* 174: 106657.

referred to as the "exit option" by Hirschman, can provide a powerful feedback in competitive markets. Widespread use of the exit option by dissatisfied customers (i.e., choosing another firm's product) motivates firms to compete by improving their performance to address customer retention. However, such an exit-driven competition *between* organizations is not always available to self-governing groups for CPRs due to formal and informal entry barriers. Thus, an alternative feedback mechanism *within* organizations is further required for resource users to respond to decline in the effectiveness of CPR management.

This study conducts a comparative analysis of an internally-driven feedback mechanism that relies on the active participation and expression of opinions and needs by members — members exercise the so-called "voice option" (Hirschman 1970) to express concerns over a decline in organizational performance and correct their problems by themselves. The voice option not only takes a variety of forms (i.e., petitioning and mobilizing public opinion), but also provides an uncertain benefit because performance improvement often requires collective efforts to fix problems (Hirschman 1970). Thus, for the voice-driven feedback mechanism to be effective, institutions need to be structured to help reduce the cost of voice and provide a protocol on how to deal with issues raised by members.

Further, CPR scholars have noted that context matters to explain the effectiveness of institutional design, i.e., a particular set of institutional arrangements that perform well under one social-ecological setting will not necessarily be effective in a different social-ecological setting (Folke et al. 2007; Epstein et al. 2015; Janssen and Anderies 2013; Young 2002). The recognition of the importance of the fit of institutional arrangements with the context in which they operate suggests that the effectiveness of voice option in a self-governing organization may be determined by how its rules for voicing interact with underlying social and ecological variables. Thus, the complexity of the voice-driven feedback mechanism and its apparent importance to the self-governance of CPRs raises an important question: under what set of institutional and contextual conditions will the voice option work effectively to enhance organizational performance towards CPR sustainability?

I address this question by examining 30 fishing groups in South Korea that have implemented voice-promoting institutions under different social and ecological conditions. In this study, I focus on the voice-promoting institutions associated with the violation of rules for regulating resource overuse. Because widespread violation of such rules is detrimental to CPR sustainability, it is important for members to express concerns and make their voice heard about who violated rules, what level of sanction is appropriate for the offender, and how to coordinate various interpretations of what constitutes rule infractions. Specifically, I identify voice-promoting institutions as Ostrom's three design principles (DPs): DP 4 (monitoring), DP 5 (graduated sanctioning), and DP 6 (conflict-resolution mechanisms).

Although all the three DPs have been considered as critical institutions for controlling rule infractions (Ostrom 1990; Anderies, Janssen, and Ostrom 2004) by members themselves, a need for more research on this view was suggested by some counterintuitive findings. For instance, graduated sanctioning is seldom found in archival records of long-enduring CPR systems and, furthermore, the investment into making graduated sanctions work appears to be inversely correlated with the longevity of a CPR

(De Moor 2018). One of the major lessons from these recent findings is that each of the DPs could be one of multiple institutional components that may or may not be necessary for successful self-governance.

To develop nuanced understanding of the relationship between rule-enforcing institutions and CPR systems, I base my approach on the notion that institutional arrangements associated with rule enforcement can vary by specific case because of the spillover effect of biophysical and social contexts on reducing transaction costs for rule enforcement (Anderies, Janssen, and Schlager 2016; Muneepeerakul and Anderies 2017). I focus on resource stationarity (biophysical context) and group size (social context), both of which have often turned out to be effective in decreasing costs of monitoring and communication. For example, compared to a small size group with a high dependence on stationary resources, it is more costly for a large size group to monitor an overuse of mobile resource units (e.g., Schlager, Blomquist, and Tang 1994; Yang et al. 2013). Thus, it can be predicted that organized monitoring activity (namely, the presence of DP 4) is less critical to CPR sustainability for small size groups that rely on stationary resource units.

This study aims to generate empirically-derived hypotheses about the fit or alignment among resource stationarity, group size, and the voice-promoting institutions. To this end, I conducted a qualitative comparative analysis (QCA) that allows us to investigate multiple configurations of institutional and contextual conditions that are likely to lead to successful self-governance (Ragin 2008; Benoît Rihoux and De Meur 2009). Each configuration generated by QCA consists of a distinctive set of institutional and contextual conditions. Hence, a close examination of each configuration and cross-configuration comparisons would allow a better understanding of how institutional arrangements and resource mobility and group size conditions collectively determine the outcomes of self-governance of CPR. My comparative analysis is based on filed reports on the 30 fishing groups participating in South Korea's ongoing marine resource policy (Self-Governing Fishery Policy, hereafter SFP). The fishing groups have established membership rules that require candidate members to meet several conditions, such as length of stay, admission fee, and member consent. In addition to the institutional barriers to membership change, community-level rules for regulating rule infractions were crafted by the group members themselves. The SFP also required each group to decide and report membership size and the mobility of appropriated resources. Hence, these 30 fishing groups provide sources of empirical data to assess the fit of voice-promoting institutions with social-ecological contexts.

This study first explains the role of DP 4, 5, and 6 in promoting the voice option, then reviews insights from CPR literature leading to a need for investigating the institutional fit. In Section 3, I provide a detailed outline of my research strategy, including case selection, data collection, the use of QCA, and the protocol used to measure successful self-governance and the feedback-related conditions.

The remaining sections proceed with my empirical findings and discussions on them. I found seven different combinations of institutional and contextual conditions that are likely to be linked to successful self-governance. Those combinatorial results indicate that there is no stereotyped design of institutional arrangements for self-controlling rule violations. Finally, the discussion focuses on each combination to address what institutional conditions are fitted well with stationary resources and/or small size groups.

3.2. Theoretical Foundations

This work builds on the empirical institutional analysis tradition of Elinor Ostrom and conceives of the relationship between institutions and context through the institutional Design Principles. Ostrom (1990) extracted 8 design principles from the comparison of many small scale social-ecological systems (SESs). These design principles can be viewed as prescriptions for the design of effective feedback control mechanisms in SES (Anderies, Janssen, and Schlager 2016). Here I investigate a subset of the design principles as foundations for a particular type of feedback mechanism based on the notion of 'voice'.

3.2.1. Voice-Promoting Institutions: Ostrom's Design Principles

Self-governing organizations make and enforce a set of rules for regulating how to withdraw shared resources and how to mobilize money and labor to maintain and operate natural and built infrastructures (Ostrom 1990). However, members may be tempted to not keep the rules because everyone enjoys the benefits of following these rules (i.e., abundant resources) while the benefits of violating the rules are private and excludable (i.e., private gains from cheating). They may contribute less to infrastructure maintenance and may also overharvest shared resources. To overcome the free-riding and over-exploitation problems, CPR theories emphasize that feedback mechanisms should be designed to self-control rule infractions (Ostrom 1990; Anderies and Janssen 2013;

Anderies, Janssen, and Ostrom 2004). A core set of institutional arrangements for the feedback process has been identified as Ostrom's DP 4 (monitoring), 5 (graduated sanctioning), and 6 (conflict-resolution mechanisms): (1) DP 4 states that "Monitors, who actively audit CPR conditions and appropriator behavior, are accountable to the appropriators or are the appropriators" (Ostrom 1990, 93); (2) DP 5 states that "Appropriators who violate operational rules are likely to be assessed graduated sanctions (depending on the seriousness and context of the offense) by other appropriators, by officials accountable to these appropriators, or by both" (Ostrom 1990, 94); and (3) DP 6 states that "Appropriators and their officials have rapid access to low-cost local arenas to resolve conflicts among appropriators or between appropriators and officials" (Ostrom 1990, 100).

These institutional DPs not only reduce the cost of the voice option, but also enhance the effectiveness of the voice option for members in three positions: monitors, punishers, and arbitrators. First, the voice option exercised by monitors is notifying their group of rule infractions. This voice option plays a role in alerting members that rule infractions can be detected, thereby helping decide to whether or not to adhere to the rules (Ostrom 1990). However, members face challenges in choosing the voice option in terms of both costs and benefits (Hirschman 1970). This is because it is certain that members should invest personal resources in exercising the voice option while it is uncertain whether and how much they can benefit from the investment. Ostrom's DP 4 (monitoring) helps address these challenges in ways that members share the costs of voice and/or increase the personal benefits of voice. For instance, the fishing-site rotation system motivates a fisher waiting his rotation turn to monitor the fisher using the same site right before his turn (Ostrom 1990). This helps other fishers to save their time and money invested in detecting and reporting cheaters. Similarly, private benefits are given to monitors based on their performance (Ostrom 1990). They can gain economic rewards (i.e., portion of the fines collected from cheaters) and social reputations (i.e., protector of the CPRs). Such personal rewards incentivize monitors to notify other members of how rules are violated by whom.

The second type of voice is exercised by members holding the position of punisher. Hirschman (1970) argues that voice can put direct pressure on those who have committed misbehavior. In self-governing organizations, such pressures are brought upon rule violators in a variety of forms ranging from small fines to banishment (Ostrom 1990). Hirschman stresses that in order for these pressures to take effect, it is necessary to allow rule violators some leeway for self-correction. His main concern is the "possibility of the negative returns to voice" (Hirschman 1970, 31), which means that voice that exerts excessive pressure on wrong-doers may backfire by discouraging them from correcting their behavior (Hirschman 1970). To prevent the negative returns to voice, Ostrom's DP 5 (graduated sanctioning) can facilitate the matching of members' demands for punishment with the context and seriousness of the offense. Therefore, institutionalizing the graduated sanctions can reduce excessive punishments that do not reflect circumstantial considerations.

Lastly, the voice option exercised by arbitrators is articulating their opinions to resolve conflicts arising from rule enforcement. Because different members can interpret a rule very differently even if the rule is quite simple, it is difficult to have a shared understanding of whether a certain member has indeed violated a rule and how serious the rule infraction is. Such varied interpretations of what constitutes a rule infraction are likely to lead to internal conflicts over rule enforcement among members (Ostrom 1990). To help resolve these conflicts, members need to have the opportunity to make their voice heard about how the rule violation was dealt with in the past and what the legitimate interpretations of the rules are. Ostrom's DP 6 (conflict-resolution mechanisms) enables members to exercise the voice option by getting members involved in discussing acceptable ways of interpreting the rule. DP 6 is indispensable to the consistent and shared understanding of fair enforcement that allows for long-run maintenance of complex system of rules (Ostrom 1990).

3.2.2. The Fit of Institutions with Social-Ecological Contexts

CPR scholars have increasingly recognized that a reasonable fit between institutions and contextual attributes is central to effective environmental governance (Ostrom 2010; Young 2002; Lebel et al. 2013). The concept of institutional fit highlights that the performance of an institution depends on how well the institution is matched to social and ecological features of governance problems it was meant to address (Epstein et al. 2015). In this study, a specific problem of CPR governance was identified as the violation of rules for regulating resource overuse. Accordingly, institutions of interest in this paper are Ostrom's three DPs (DP 4, 5, and 6) aimed at monitoring rule violators, imposing gradual sanctions on them, and resolving conflicts over different interpretations of rules, respectively.

The remaining elements, which I need to identify to explore the institutional fit, are biophysical and social contexts in which the rule infraction problem is embedded. Identifying the full set of contextual variables that interact with particular institutions is a significant challenge for CPR scholars due to typically small sample sizes that make it difficult for statistical models to use interaction terms. (Agrawal 2003; Epstein, Vogt, and Cox 2014). A promising approach to this methodological issue is qualitative comparative analysis that allows researchers to make use of small- and intermediate-N cases to investigate institution-context interactions and their outcomes (Basurto 2013; Rudel 2008; Epstein et al. 2015).

To better understand the fit between the three institutional DPs and contextual attributes of the rule infraction problems, this study examines 30 self-governing fishing groups with a focus on resource stationarity and group size. These two contextual variables have often turned out to be relevant to sustainable CPR management (Wade 1994; Baland and Platteau 1996; Ostrom 2009). The dynamics of stationary resource units is more predictable than that of mobile resource units. Hence, stationary resource units are in general more readily monitored so that they can be governed with lower information and transaction costs than mobile resources (Schlager, Blomquist, and Tang 1994; Gutiérrez, Hilborn, and Defeo 2011; Agrawal 2001).

On the other hand, there are the pros and cons of a given size of group in terms of transaction costs of and available resources for monitoring and enforcement (Yang et al. 2013). Monitoring can be less costly in small groups because cheaters are more visible whereas additional resources invested in rule enforcement may be more limited in small groups (e.g., Agrawal & Goyal, 2001; Boyd, Gintis, & Bowles, 2010; Esteban & Ray, 2001; Olson, 1965; Tucker, 2010).

The role of contextual variables motivated us to further examine whether the presence (or absence) of a particular contextual condition can make an institutional condition less (or more) important to successful self-governance. Indeed, a deductive hypothesis was presented that the effect of institutions associated with monitoring and enforcement may be reduced in a small group appropriating stationary resources (Agrawal 2001). Yet, within the CPR literature, there has been little empirical research into the interactions between institutions (DP 4, 5, and 6) that address rule infraction problems and social-ecological contexts (resource stationarity and group size) in which the problems are embedded.

Using a qualitative comparative analysis (Ragin 2008), this study aims to enrich our understanding of possible combinations of institutional and contextual conditions that contribute to successful self-governance of fisheries. Because such combinations represent different pathways towards successful self-governance, all of them can be characterized by a fit of the institutional arrangements to contextual attributes in terms of better social and ecological outcomes.

3.3. Research Strategy

This section details how I selected cases to be studied and collected data on the selected cases. Additionally, I explain why QCA is an appropriate analytical tool for studying institutional fit. Finally, I explain how I measured outcomes and coded institutional and contextual conditions.

3.3.1. Case Selection and Data Collection

This study is based on secondary analysis of existing data on 30 fishing groups in South Korea. The primary data was collected during 2010-2012 when undergraduate students who took the *Public Choice Theory* course at Seoul National University conducted field observations of 41 self-governing fishing groups in South Korea. The instructor of the course was an advisee of the late Elinor Ostrom and is part of the Bloomington School of institutional analysis (T.K. Ahn). Each fieldwork team, which consisted of up to six students, autonomously selected 1-4 cases of fishing groups, leading to a total of 41 cases to be studied. Upon the completion of field visits, each team submitted a field report that evaluated whether Ostrom's eight DPs were present in the fishing groups. The reports also provided basic information of social-ecological conditions, such as how many members are in a group and whether their resource systems had been improved or not.

For my study, I used a two-stage process narrow down the 41 fishing groups to 30 groups (see Appendix A.1 for more details on group names and locations). First, I only selected the groups that participated in the Self-Governing Fishery Policy (SFP) in which participant fishing groups that perform better in terms of collective action for resource system maintenance are financially rewarded by the central government. Note that fishing groups could choose not to participate in the SFP if they wanted. Such monetary incentives might further motivate fishing groups to enhance the level of cooperation to improve group performance. As such, groups participating in the SFP were exposed to the monetary incentives associated with enhanced cooperation, while those opting out had no such direct incentives. In order to rule out potential differences in group performance stemming from the monetary incentives, I excluded fishing groups that have not participated in the SFP. Second, I examined the quality of the field reports written by the field teams. Since the field work aimed to evaluate whether Ostrom's eight DPs are present in the fishing groups, not all field reports are informative enough to answer the coding questions (see Appendix A.2 for more details on coding questions). For example, some field reports provide sufficient data on social outcomes (e.g., trust level, rule compliance, and economic equity) but not enough ecological data, or vice versa. I excluded the fishing groups that reported missing values that are critical to measuring the outcome and the conditions of my interest.

The secondary nature of my data, however, does not mean limitations in the quality of the data that I worked with. This stems from the rigor with which the primary data was collected. Prior to their field visits, the field workers had to extensively read and discuss the main course textbook *Governing the Commons* (Ostrom 1990) in order to understand how to define each DP and describe social-ecological contexts in CPR cases. Data were collected mostly through in-person, semi-structured interviews with current or former leaders and other members of fishing groups. The interviews were conducted during field visits that lasted one or two days. Open-ended questions for the interviews were not provided by the lecturer, but rather were created at the discretion of each fieldwork team to collect qualitative data on the eight DPs and basic social-ecological conditions. The interviews were summarized in the field reports (10-30 pages). These reports were used as major data sources in the current research. The field reports provide in-depth descriptions of not only institutional conditions (i.e., DP 4, 5, and 6) but also biophysical and social contexts including group size, appropriated resources, the condition of natural infrastructures (i.e., mudflat), rule compliance, the level of trust, and leadership. Besides the field reports, many fieldwork teams submitted their interview files in an audio or text format. They also obtained community-level rule documents with the consent of the fishing groups. I used all the available materials to code the outcome variables (see Table A.2 in Appendix A) and institutional and social-ecological conditions (see Table A.3 in Appendix A).

3.3.2. Analytical Approach: csQCA

QCA is a case-oriented, set-theoretic method that helps explore causal relationships between conditions (similar to independent variables) and an outcome (similar to dependent variable) (Ragin 2008; Jordan et al. 2011). An assumption of causation underlying QCA, differing from traditional statistical methods, is that a given condition might be necessary or sufficient for an outcome (Katz, Hau, and Mahoney 2005). For instance, regression analysis is based on the linear causation assumption that allows researchers to estimate the net, independent effect of each explanatory variable on a dependent variable. Unlike the "net effects thinking" (Ragin 2008) based on linear algebra, QCA uses Boolean algebra to address causal complexity based on three logical features (Schneider and Wagemann 2012; Fiss, Sharapov, and Cronqvist 2013; Grofman and Schneider 2009; Jordan et al. 2011). First, *conjunctural* causation represents that a combination of conditions as well as a single condition might generate an outcome. QCA results show that the conditions constituting a combination are connected to each other through logical AND operator or Boolean multiplication "*". Second, *equifinal* causation means that different combinations of conditions might lead to the same outcome. QCA results show that the multiple combinations leading to the same outcome are connected to each other through logical OR operator or Boolean addition "+". Third, *asymmetric* causation indicates that if the presence of a condition leads to the occurrence of an outcome, then the absence of the condition does not necessarily lead to the non-occurrence of the outcome. QCA results express the absence of conditions or an outcome as logical NOT operator or Boolean negation "~".

The ability of QCA to capture these three features of casual complexity makes QCA a powerful analytical tool for investigating different combinations of conditions that lead to a given outcome (Jordan et al. 2011). Instead of focusing on how the presence or absence of individual conditions changes the probability of successful self-governance, I am more interested in identifying which combinations of such conditions are sufficient for successful self-governance. Hence, QCA is well suited to addressing my research question in comparison to logistic regression analysis.

Among three major types of QCA (crisp-set, fuzzy-set, and multi-value QCA), I used crisp-set QCA (csQCA) that requires dichotomously coded datasets (i.e., 0 or 1). The dichotomization of data can result in a loss of most of information and must be done through a justifiable cutoff value if a research uses fine-grained *quantitative* data, such as physical size and annual income (Goldthorpe 1997). However, the interview data used for this study are mostly of a *qualitative* nature (e.g., mudflat where clams live is in good condition, and the level of trust remains high). In addition, most of the conditions and outcome of my interest are better measured by capturing differences in *kind* (i.e., presence or absence of a DP, and success or not-success) between fishing groups rather than differences in *degree*. Furthermore, using dichotomized values can facilitate the replicability of the existing analysis by other scholars because dichotomization forces researchers to choose a clear threshold to capture differences in kind (Benoit Rihoux and Ragin 2009).

For csQCA of 30 fishing groups in South Korea, I chose DP 4 (monitoring), DP 5 (graduated sanctioning), DP 6 (conflict resolution mechanisms), and two social-ecological conditions (resource stationarity and group size). Using a software tool (fsQCA 3.0) developed for QCA (Ragin and Davey 2016), my cross-comparison of the fishing groups produces logically minimal combinations of conditions that are sufficient for successful self-governance in the sample at hand (Benoît Rihoux and De Meur 2009). These logically simplified configurations, which are called *solution terms*, are set-theoretically expressed through three logical operators, such as AND, OR, and NOT. Based on a shared guide to good practice in QCA (Ragin 2008; Schneider and Wagemann 2012; Benoît Rihoux and De Meur 2009), Appendix A.3 describes several key steps I took to identify solution terms, and furthermore, reports a raw table, a truth table, and how to deal with logical remainders (which are defined as empirically unobserved but logically possible combinations of conditions).

A close look at the solution terms allows researchers to establish the conditions of necessity and sufficiency (Ragin and Davey 2017). A condition is necessary but not sufficient if it is capable of producing an outcome in combination with other conditions and appears in all solution terms. A condition is sufficient but not necessary if it exists in a certain solution term but is not the only one condition of the solution term. A condition is both necessary and sufficient if it is the one and only condition (i.e., not a combination of conditions) that produces an outcome. In the next two subsections, I describe more details on the outcome (success or not-success) and the institutional and social-ecological conditions that are linked to the outcome.

3.3.3. The Outcome: Successful Self-Governance

I used the case data to examine both ecological and social outcomes of the fishing groups. I, then, used these outcomes to assess overall self-governance level (success vs. not success) of the fishing groups. Measures of ecological and social outcomes were identified through 10 CPR variables (see Table A.2 in Appendix A).

These CPR variables are drawn from two coding manuals, both of which were developed by the Workshop in Political Theory and Policy Analysis at Indiana University (Ostrom et al. 1989) and by the Center for Behavior, Institutions and the Environment at Arizona State University (Ratajczyk et al. 2016). Table 3.1 shows what variables are used to evaluate ecological and social outcomes, and how the coding results of the variables were aggregated to assess overall self-governance level of each fishing group. Based on the measures of ecological and social outcomes, a self-governing group is assessed to be successful if it has *neither* declined in ecological outcomes *nor* had social conflict issues associated with rule compliance, equity, and trust. Otherwise, it is assessed to be not successful. All of the coding results of 10 outcome variables and overall assessments ("success" or "not success") are provided in Table A.4 in Appendix A.

Table 3.1. Measures of ecological and social outcomes and overall success.

Ecological Outcomes	Assessed as "not declined" unless the resource balance has become worse (Variables 1 and 2) *and* the condition of natural infrastructure has worsened (Variable 3) • Variable 1: Resource balance at the beginning of a period • Variable 2: Resource balance at the end of a period • Variable 3: Changes in condition of natural infrastructure during this period
Social Outcomes	Assessed as "no conflict issues" only when the rule of law (Variables 4 and 5), equity (Variables 6 and 7), and trust (Variables 8, 9, and 10) are *all* assessed as "good"
Rule of Law (Political Indicator)	Assessed as "good" unless more than half of the members violate both resource appropriation (Variable 4) *and* provision rules (Variable 5) • Variable 4: Following appropriation rules • Variable 5: Following provision rules
Equity (Economic Indicator)	Assessed as "good" unless there are both disadvantaged (Variable 6) *and* worst off (Variable 7) members of the fishing groups • Variable 6: Disadvantaged appropriators • Variable 7: Harm to those who are worst off
Trust (Social Indicator)	Assessed as "good" if the level of trust has remained high (Variables 8 and 9) *or* has improved among appropriators (Variable 10) • Variable 8: Levels of trust at the beginning of a period • Variable 9: Levels of trust at the end of a period • Variable 10: Changes in trust level during this period
Overall assessment of self-governance	Assessed as "success" if 1) ecological outcomes are assessed as "not declined" *and* 2) social outcomes as "no conflict issues"; otherwise, "not success".

† More details on ten outcome variables and overall assessments are provided in Appendix A.

To assess ecological outcomes, I consider the state of the resource system as indicated by the resource balance and the condition of natural infrastructure (i.e., seaweed breeding rocks and harmful organisms) affecting the replenishment of the resource stock.

I use three CPR variables to measure the state of resource system: Variables 1 and 2 for the resource balance, and Variable 3 for the condition of natural infrastructure (see Table 3.1). Variables 1 and 2 are used to assess the balance of resource availability and withdrawal at the beginning of and the end of a time period, respectively.

The resource balance is coded to range from extreme shortage to quite abundant. The period of interest for this study is from when a self-governing fishing group began its participation in the Self-Governing Fishery Policy (SFP) to when the fieldwork was done. I coded Variables 1 and 2 using textual information collected from the interviews with fishing groups leaders and/or members. For example, the interviewees said that clams living in the mudflat are still abundant because individuals were able to harvest a constant amount of clams, or that a shortage of clams was recognized at the beginning of the period because the withdrawn amount of clams was lower than before. Note that each fishing group joining the SFP decided what species to be caught, then reported a group of species to the Korean government. To code the resource balance, I examined the reported species that could be stationary, mobile, or both.

I also coded Variable 3 to examine whether the condition of natural infrastructure (i.e., fishing grounds) has been improved, remained the same, or worsened during the same period. The field reports and interview files show that several fishing groups engaged in activities to improve the quality of natural infrastructure: clearing marine debris, removing harmful organisms in fishing grounds, scraping seaweed breeding rocks, stocking fishing grounds with juvenile fish, and periodically closing fishing grounds. Based on the coding results of Variable 1, 2, and 3, ecological outcomes are assessed as "not declined" unless the resource balance has become worse *and* the condition of natural infrastructure has worsened.

To evaluate social outcomes, I established three indicators (rule of law, equity, and trust) whose decline can lead to social conflicts among members (see Table 3.1). First, a political indicator is the rule of law which is defined as the influence of self-crafted community rules on members' behaviors. I assessed the rule of law using two variables which indicate the rule compliance rates associated with resource appropriation (Variable 4) and resource provision (Variable 5). The rule of law is assessed as "good" unless more than half of the members violate both resource appropriation *and* provision rules. Note that measures of the rule compliance rates are based on how the interviewees characterize the usual behavior of the members with respect to community-level rules for managing CPRs.

Second, equity is an economic indicator that is critical to achieving social cohesion. I characterized the economic equity by examining whether there are members who have been consistently disadvantaged (Variable 6) and whether there are the relatively worst off who have been excluded from the process of benefit distribution (Variable 7). Nearly all the fishing groups reported that every member withdrew an equal amount of resource units or the fishing group's profit was shared equally. The equity is assessed as "good" unless both the disadvantaged *and* the worst off are in fishing groups.

Third, a social indicator is the trust that helps reduce transaction costs involving in fulfilling oral promises and enforcing community rules. I characterized the trust level among resource users at the beginning of and the end of the period in question (Variables 8 and 9) and changes in trust level during the period (Variable 10). In a few fishing groups, the trust level had worsened due to the conflicts between subgroups or the misappropriation of community funds. The trust is assessed as "good" if the level of trust has improved or remained high among members during the period of my interest. Finally, I evaluated social outcomes as "no conflict issues" if the three indicators (rule of law, equity, and trust) are *all* assessed as "good."

3.3.4. The Seven Social-Ecological and Institutional Conditions

I considered institutional and contextual conditions that are linked to successful self-governance. As shown in Table 3.2, these conditions include rule-enforcing institutions (DP 4, 5, and 6), biophysical context (resource stationarity), and social context (group size). In this subsection, I explain how these conditions are measured and coded (see Table A.3 in Appendix A for details on coding questions).

A major analytical challenge for the study of institutional fit is to identify biophysical and social contexts that affect institutional arrangements (Epstein et al. 2015). One way of addressing this challenge is to advance understanding of the role of contextual variables in making regulatory feedback processes less costly (Anderies and Janssen 2013; Janssen and Anderies 2013).

To characterize the role of social-ecological contexts, I took three strategies in measuring institutional and contextual conditions: (1) to split DP 4 (monitoring) into "organized" and "by-product" monitoring to capture whether monitoring costs are reduced either by consciously-designed rules for the sake of monitoring or by a spillover from biophysical infrastructures and other rules that are not aimed directly at monitoring;

(2) to split DP 6 (conflict-resolution mechanisms) into "formal" and "informal" mechanisms to distinguish formal meetings opened to all members from informal meetings led by group leaders with a small number of direct stakeholders; (3) to include resource stationarity and group size as contextual conditions that may affect the emergence of more effective combinations of institutional conditions.

Table 3.2. Descriptions and measures of the seven conditions.

Contextual conditions	**Description and measures**
Only Stationary Resources (ONSTAR)	The presence of ONSTAR means that group members withdraw only stationary resource units. The presence and absence of ONSTAR are coded as "1" and "0", respectively.
Group size (LTE100)	The presence of LTE100 means that group members are less than or equal to 100. The presence and absence of LTE100 are coded as "1" and "0", respectively.
Institutional conditions	**Description and measures**
DP 4: organized monitoring (OZMON)	The presence of OZMON means that group members themselves form monitoring teams and/or hire third-party monitors. The presence and absence of OZMON are coded as "1" and "0", respectively.
DP 4: by-product monitoring (BYMON)	The presence of BYMON means that monitoring is a spillover from biophysical conditions (e.g., small ports/fishing grounds) and social contexts (e.g., appropriation rules) that are conducive to mutual monitoring. Note that resource stationarity is not considered as a biophysical condition that results in by-product monitoring. The presence and absence of BYMON are coded as "1" and "0", respectively.
DP 5: graduated sanctions (GSANC)	The presence of GSANC means that group members who violate operation rules are likely to be assessed graduated sanctions (depending on the seriousness and context of the offense) by other members, officials accountable to these appropriators, or both. The presence and absence of GSANC coded as "1" and "0", respectively.
DP 6: formal conflict-resolution mechanisms (FCON)	The presence of FCON means that all group members have access to formal arenas (e.g., community meeting) to resolve conflicts among members. The presence and absence of FCON are coded as "1" and "0", respectively.
DP 6: informal conflict-resolution mechanisms (IFCON)	The presence of IFCON means that a few members who are directly related to the conflict have access to informal arenas (e.g., round table dinner) where group leaders play an active role in settling disputes. The presence and absence of IFCON are coded as "1" and "0", respectively.

Organized and By-Product Monitoring

The first strategy helps better understand the biophysical and social leverage on reducing the cost of monitoring. Several empirical studies on the commons classified monitoring activities according to which one is monitored between time and quantity (Schlager, Blomquist, and Tang 1994; Yu et al. 2016). Monitors keep watching on how many hours resource users withdraw resource units (time-based monitoring) or how many units per day are withdrawn (quantity-based monitoring). Although these types of monitoring may result in reducing the cost of monitoring, they provide little, if any, information regarding what biophysical and social contexts contributed to reducing the cost. Instead of what should be monitored, my classification is based on what enables members to monitor cheaters efficiently.

"Organized" monitoring (OZMON) is defined as monitoring activities conducted by monitoring teams consisting of resource users themselves and/or third-party monitors hired by resource users. This form of monitoring activities is organized through special rules and technologies (i.e., rotational patrolling and closed-circuit televisions) for the sake of monitoring itself. But on the other hand, "by-product" monitoring (BYMON) is a spillover from biophysical and social structures that are not consciously designed, but conducive to low-cost mutual monitoring. For instance, small size of mudflats and ports can result in high public visibility of opportunistic behaviors, thereby helping observers obtain information about rule compliance rates at low cost. Besides these biophysical conditions, the costs and benefits of monitoring are dependent of a particular set of appropriation rules governing how to get individual gains from shared resources (Ostrom

1990). For example, many fishing villages of South Korea have enforced the appropriation rule for carrying resource units to the same local marketplace and selling them jointly and simultaneously. As prohibiting individual sale of resources, such appropriation rule can make it higher a chance to catch cheaters without additional investments in monitoring activities.

Formal and Informal Mechanism of Conflict Resolution

Conflicts between appropriators are resolved not only through formal mechanisms (e.g., community meetings), but also through quite informal mechanisms led by legitimate community leaders (Ostrom 1990). The role of leadership in promoting communication to resolve conflicts was also turned out as the most significant factor of successful fisheries by statistical analysis of 130 co-managed fisheries (Gutiérrez, Hilborn, and Defeo 2011). The procedural difference between formal and informal mechanisms is how many members can participate in discussing what constitutes a rule infraction. "Formal" mechanisms of conflict resolution (FCON) allow all members to hear about an incident and articulate their opinions in public arena. This open discussion can enhance the legitimacy of decision-making, but on the other hand "the possibility of negative returns to voice making their appearance at some point is by no means to be excluded" (Hirschman 1970, 31). In other words, excessive and ferocious voice may lead to failure in making a shared understanding of even a simple rule, thereby exacerbating the conflicts at issue. Hence, "informal" mechanisms of conflict resolution (IFCON) involving a small number of direct stakeholders can become more effective as locally influential leaders are able to help the dispute settled in a more context-specific and sophisticated manner.

Resource Stationarity and Group Size

I measured resource stationarity (ONSTAR) as "1" if self-governing organizations withdraw only stationary resource units and as "0" if the withdrawn resources include mobile resource units. All the fishing groups I investigated have participated in the Self-Governing Fishery Policy (SFP) that asked them to decide and report whether to withdraw only stationary resources (e.g., seaweed and shellfish), only mobile resources (e.g., small octopus, hickory shad, and blue crab), or both. Because the fishing groups were asked to choose one of the three resource types, measures of resource stationarity were identified easily and reliably through the field reports.

The SFP also requires fishing groups to annually report membership size to central and local governments since the size is one of the criteria for group performance evaluation. This helped fieldwork teams collect reliable data on how many members belong to each fishing group. I operationalized group size as a dichotomous variable: Group size (LTE100) is coded as "1" if members are less than or equal to 100; otherwise, "0". The reference point 100 was chosen not because of a substantive principle that draws the line between small and large groups, but because of the methodological consideration that QCA recommends enough variation for each condition (in general, at least 1/3 of each value) in a truth table (Benoît Rihoux and De Meur 2009). The truth table (Table A.5 in Appendix A) shows that percentages of "0" and "1" for LTE100 are 34.8 and 65.2, respectively. Using the set of coding questions shown in Appendix A.2, two of the authors independently measured the seven conditions as well as the outcome variables. They discussed any discrepancy between their coding results to reach a consensus on the differing coding results. Cohen's Kappa score (Cohen 1960), a widely used measure for assessing inter-coder reliability, was calculated and turned out to be acceptable (see Appendix A.2).

3.4. Results and Discussion

My QCA results are based on the following basic model that relates organizational performance to the seven causal conditions:

$$Success = f\left(\underbrace{ONSTAR, GS100,}_{contextual\ conditions}\ \underbrace{OZMON, BYMON, GSANC, FCON, IFCON}_{institutional\ conditions(DPs)}\right)$$

Note that this model is not aimed at estimating the linear effects of independent variables on the outcome (so-called "net effects"), but at generating empirical hypotheses regarding how the conditions are combined with each other in the sample to produce the outcome. The hypotheses are suggested in the form of seven different combinations of contextual and institutional conditions that are likely to lead to successful self-governance (Table 3.3). Based on the different paths to the outcome, my discussion focuses on under what contextual conditions the DPs become sufficient, necessary, or irrelevant institutions for successful self-governance.

3.4.1. Data Description

Fig. 3.1 shows the tally of fishing groups that are determined to be successful in self-governance and have each condition. There are no missing values of the outcome and the seven conditions. Of the 30 fishing groups analyzed, 20 groups are successful in CPR management and the remaining ones are not (see Table A.6 in Appendix A for more details).

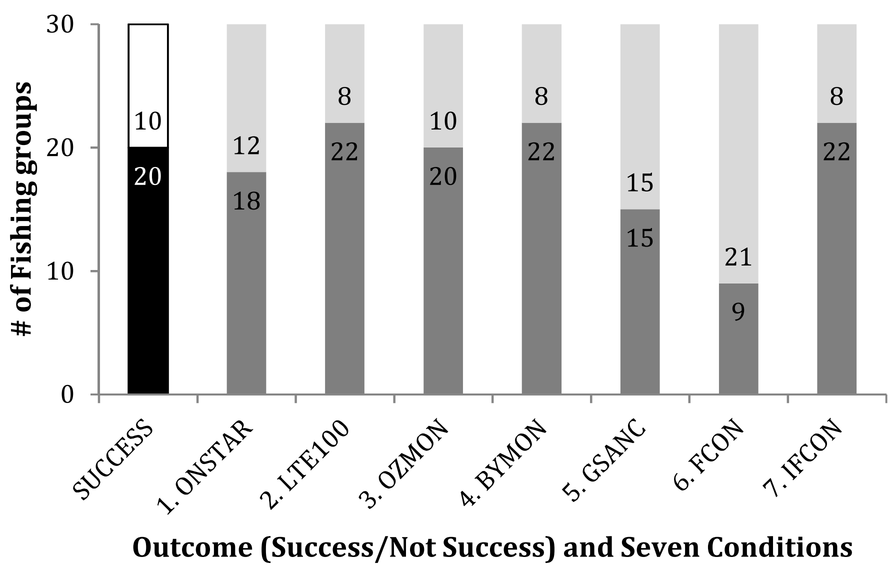

Figure 3.1. Frequency of distribution across outcomes and conditions. X-axis represents outcome (SUCCESS) and seven conditions (ONSTAR to IFCON), and Y-axis the number of fishing groups. The outcome is assessed as either Success (black) or Not-Success (white), and each condition is dichotomously measured as Presence (dark gray)/Absence (light gray).

With respect to two contextual conditions, 18 groups catch only stationary resources (ONSTAR) and 22 groups have less than or equal to 100 members (LTE100).

Among five institutional conditions, the formal mechanism for conflict resolutions (FCON) is hardly found among the groups while the informal conflict-resolution mechanism (IFCON) is one of the most-found institutional condition. Half of the 30 fishing groups impose graduated sanctions (GSANC) on rule violators. At least 20 groups monitor cheaters by organized monitoring (OZMON) or by-product monitoring (BYMON). A cross tabulation was provided between the success/not-success of self-governance and the presence/absence of each condition (see Table A.7 in Appendix A).

Fig. 3.2 depicts how many institutional conditions are met in successful (black) and unsuccessful (white) groups, respectively. Comparing these two groups indicates a trend of the relationship between the outcome (success/not-success) and the number of institutional conditions. Most of the successful groups (17 of 20) have at least three institutional conditions whereas most unsuccessful groups (8 of 10) have less than three institutional conditions.

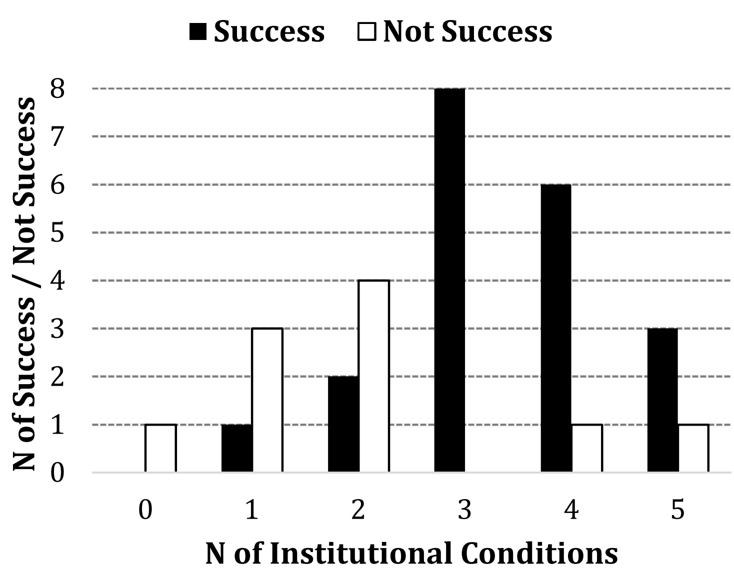

Figure 3.2. Quantitative trends in institutional conditions and outcomes. X-axis represents the number of institutions for self-controlling rule infractions, and Y-axis the number of

successful/unsuccessful fishing groups. Most of the successful groups (black) have three or more institutional conditions while most of unsuccessful groups (white) have less than three institutional conditions.

Although Fig 3.2 shows the quantitative trend in successful self-governance and institutional conditions, it provides no qualitative information about what kinds of institutional conditions are well fitted with contextual conditions. The lack of knowledge of the interaction between institutions and contexts makes it particularly difficult to explain how the groups with less than three institutional conditions are successful (see two left-end black bars in Fig. 3.2). In the next subsection, I use csQCA to identify the fit of institutions with social-ecological contexts in forms of set-theoretic relationships between the outcome and the seven conditions (i.e., what conditions are sufficient and necessary for successful self-governance).

3.4.2. The Seven Combinations of Conditions

The csQCA results present a solution formula consisting of the seven combinations (C1 to C7 in Table 3.3) linked to successful self-governance. Such combinations are called solution terms that are connected to each other through the logical operator OR ("+"). C1 suggests that if a small-size fishing group (≤ 100 members) manages only stationary resources while resolving their conflicts through informal mechanisms led by leaders, its self-governance can be successful. C2 and C3 signify that if a fishing group depending only upon stationary resources established either organized or by-product monitoring as well as informal conflict-resolution mechanisms, its self-governance can be successful despite lack of graduated sanctions. C4 reports that if a fishing group appropriating mobile resources developed organized and by-product monitoring, informal conflict-resolution mechanisms, and graduated sanctioning, then the group can be successful in self-governance.

Table 3.3. The simplified solution formula.

Successful self-governance of local fisheries		
Seven combinations (Intermediate solution†)††	Consistency	Coverage†††
(C1) **ONSTAR*LTE100***IFCON +	1	0.4
(C2) **ONSTAR***OZMON*gsanc*IFCON +	1	0.3
(C3) **ONSTAR***BYMON*gsanc*IFCON +	1	0.25
(C4) **onstar***OZMON*BYMON*GSANC*IFCON +	1	0.2
(C5) **LTE100***OZMON*GSANC*IFCON +	1	0.4
(C6) **LTE100***BYMON*GSANC*IFCON +	1	0.35
(C7) **LTE100***BYMON*FCON*IFCON	1	0.3

† As recommended by Ragin (2008), I based the combinations on the intermediate solution that requires us to use theoretical and substantive knowledge about influence of each condition on the outcome. Based on discussion about the seven conditions in Section 2 and 3, I expected that LTE100 could contribute to successful self-governance when it is present *or* absent, and that the rest of the conditions could contribute to the outcome when they are present. Using these directional expectations, the fsQCA software 3.0 (Ragin and Davey 2016) computed the intermediate solution.

†† C1 explains the success of self-governing organizations, including Group ID 1, 3, 19, 15, 16, 21, and 22; C2 does 3, 12, 15, 16, 26, and 30; C3 does 3, 11, 15, 16, and 30; C4 does 2, 9, 20, and 27; C5 does 1, 2, 4, 10, 20, 21, 22, and 27; C6 does 1, 2, 10, 18, 19, 20, and 27; and C7 does 1, 3, 10, 16, 23, and 27. Group ID is a case number assigned to each of 30 self-governing organizations (see Appendix A for more details on Group ID and locations on map). Note that the success of a group (e.g., Group 1) can be explained by multiple paths (e.g., C1, C5, C6, or C7) because of *equifinal* causation which means that different combinations of conditions might lead to the same outcome (see Subsection 3.3.2).

††† I used raw coverage defined as the number of cases following a specific path to the outcome divided by the total number of instances of the outcome (Ragin 2008).

The rest of the combinations (C5, C6, and C7) present three different combinations of institutional conditions that are likely to lead a small-size group to succeed in self-governing local fisheries. C5 and C6 differ by only one institutional condition; i.e., C5 has the organized monitoring while C6 include the by-product monitoring. C6 and C7 also differ only one institutional condition; i.e., C6 has the graduated sanctions while C7 has the formal mechanisms for conflict resolution. Five configurations that are likely to lead to unsuccessful self-governance are also reported in Appendix A (see Table A.8). These configurations are not logical mirror images of the configurations leading to successful self-governance.

QCA presents two simple measures for evaluating how strongly a set relation between each combination and successful self-governance is supported by empirically observed cases (Ragin 2008). The two measures are consistency and coverage shown in Table 3.3. Set-theoretic consistency assesses how consistently a combination leads to successful self-governance. Some self-governing groups sharing a given combination may be successful while others with the same combination may be not. A degree of such contradictions is quantified by measures of consistency. The consistency score (Ragin 2008) is simply calculated by dividing the number of successful groups with a given combination by the total number of groups with the same combination. If the consistency score is "1" (perfect consistency), it means that no contradictory outcomes are empirically observed. If this is true, all the groups with the combination are a perfect subset of successful groups: the combination is a sufficient condition for successful self-governance. As shown in Table 3.3, all seven combinations have a perfect consistency (consistency score =1). This indicates that the fishing groups I investigated should be successful in CPR management if they are characterized by one of the seven regulatory feedback mechanisms. Hence, my finding not only provides a set-theoretic basis for the existing arguments that regulatory feedback mechanisms are critical to successful self-governance, but also suggests that there could be a diversity of the mechanisms depending on different social-ecological contexts in which they are embedded.

Set-theoretic coverage is another measure for assessing a set relation between each combination and successful self-governance. Consistency described above focuses on a combination that may lead groups with the combination to be either successful or not. In contrast, coverage focuses on successful groups, some of which may follow a path (or combination) while others may follow alternative paths. Because measures of coverage for this study are interested in how many successful groups are covered (or accounted for) by each combination, the coverage score (Ragin 2008) is the proportion of successful groups following a specific path to all successful groups. In Table 3.3, my QCA results report successful groups following each path as well as the coverage scores of all paths ranging from 0.2 (i.e., C4) to 0.4 (i.e., C1 and C5). These coverage scores are much lower than the consistency score (=1) assigned to all combinations. This is not surprising because the existence of multiple paths to the same outcome can make it small the coverage of any given combination while contributing to remarkable consistency (Ragin 2006).

A low coverage path is empirically less important because the path explains only a few cases. However, QCA scholars argue that the low coverage path can be more interesting and important theoretically than high coverage paths which might be too obvious to produce new theoretical and empirical knowledge (Grofman and Schneider 2009; Schneider and Wagemann 2010). In addition, this study aims to generate theoretically and substantively informative hypotheses with intermediate N cases rather than to test ready-made hypotheses with large N cases. Hence, I decided to set a coverage threshold as the lowest score (0.2) that allows us to compare C4 (including resource mobility) to C2 and C3 (including resource stationarity). As discussed in the next subsection, such comparison contributes to generating new hypotheses regarding how resource mobility could affect institutional arrangements for rule-enforcement.

3.4.3. Discussion

Before taking a close look at each combination, I present two key theoretical implications from overall comparison of the seven configurations. First, the presence of informal conflict-resolution mechanisms (IFCON) in all the seven combinations suggests that IFCON is a necessary (but not sufficient) condition for successful self-governance of local fisheries. This finding signifies that if the leader-led informal mechanisms for conflict resolution are absent, then fishing groups will not be successful in self-governance. The result is in line with Gutiérrez et al. (2011)'s empirical identification of strong leadership as the most significant factor contributing to successful co-managed fisheries.

Second, I did not find any combinations irrelevant to both resource stationarity and group size, but rather all the combinations include the presence or the absence of at least one of the two contextual conditions. Furthermore, contextual conditions in each configuration are combined with different sets of institutional conditions. Such variations of institutional arrangements with contextual conditions support the argument that there are no context-free institutional panaceas for the success in self-governing shared resources. What matters to successful self-governance is the institutional fit with biophysical and social contexts.

Institutional Arrangements for Both Stationary Resources and Small Group Size

A comparison of C1 with other combinations demonstrates that the coexistence of stationary resources (ONSTAR) and small group (LTE100) has a positive impact on minimizing the number of institutional conditions for successful self-governance. C1 suggests that small groups appropriating only stationary resources can be successful even if rules for monitoring (OZMON and BYMON) and graduated sanctioning (GSANC) are not in use. The only one institutional condition for their success is the conflict-resolution mechanism depending heavily on community leaders' voice (IFCON). This finding not only reinforces the emphasis on the significant role of leadership in managing fisheries (Gutiérrez, Hilborn, and Defeo 2011), but also provides further information on contextual conditions under which the role of leaders in disputing conflicts can be the unique institutional factor.

Institutional Arrangements Varying with Resource Stationarity

In contrast to C1, C4 has the largest variety of institutional conditions among all the seven combinations. The combination C4 suggests that the systems depending on mobile resources can be successful if all the institutions except for the formal conflict-resolution mechanisms (FCON) have been developed. To further our understanding of how resource stationarity affects institutional arrangements for successful self-governance, I applied the Boolean algebra to C2 and C3: C2 + C3 = ONSTAR*(OZMON +

BYMON)*gsanc*IFCON. The biophysical difference between (C2 + C3) and C4 is whether only stationary resources are appropriated or not, while group size is commonly found irrelevant to successful self-governance in both (C2 + C3) and C4.

A comparison of (C2 + C3) and C4 presents two key findings on the effect of resource stationarity on institutional arrangements, especially monitoring and graduated sanctioning. First, establishing *either* organized monitoring (OZMON) *or* by-product monitoring (BYMON) is sufficient for successful self-governance in systems in which members withdraw only stationary resources. However, fishing groups dependent on mobile resources will be successful when *both* OZMON *and* BYMON are present.

Another interesting effect of resource stationarity on institutional arrangements is found on the presence/absence of graduated sanctions (GSANC). The csQCA results report that GSANC should be present for success in managing mobile resources while the groups appropriating only stationary resources can be successful even if GSANC is absent. In this study, the absence of GSANC was coded for either of two cases: no penalties on rule violations (i.e., only oral warnings are repeated); and no gradual rise in sanctions (i.e., only banishment no matter how serious rule infractions are). Indeed, some of the Korean fishing groups I analyzed have allowed members to call for only banishment whereas other groups have allowed only verbal warnings in response to rule violations. Ostrom (1990) provides fruitful insights into a potential explanation of why such polarized voice can be preferred by self-governing groups. She argues that a decision on sanctions made by self-governing groups relies on the interpretation of the context and seriousness of the offense, and such interpretation is influenced by "economic or other circumstances within CPRs" (Ostrom 1990, 99). For example, economic hardship led a Japanese forest village to become temporarily very tolerant toward resource use in violation of the appropriation rules (Ostrom 1990).

A hypothesis arising from the discussion on graduated sanctioning is that the rule simplicity resulting from the physical properties of resources can affect members' interpretations of the context and seriousness of rule violations. In general, the dynamics of stationary resource units is more predictable than that of mobile resource units (Schlager, Blomquist, and Tang 1994). As a result, compared to mobile resources, stationary resources (e.g., seaweed, oyster, and clam) are withdrawn within a clearly defined boundary and are managed by relatively simpler operational rules regulating fishing gears and methods. Therefore, it is less costly for resource users to understand and observe what to do and what not to do for sustainable governance of stationary resources. When such a simple rule is violated, there could be two opposite directional interpretation of the violation. Members may think that rule infractions were obviously caused by "honest mistakes" (Ostrom 1990, 101) or "repairable lapses" (Hirschman 1970, 1) because the rules are too simple to be violated. If this is the case, they would be very lenient enough to keep preferring verbal warnings over graduated sanctions. In contrast, members may be sure that rule infractions are attributed to seriously opportunistic behaviors because the violated rules are too simple to be violated by mistake. In this case, a very low tolerance toward rule violations could be so prevalent among members that they can consistently prefer an extreme punishment to graduated sanctions.

Institutional Arrangements for Small Group Size

Three solution terms (C5, C6, and C7) present different combinations of institutional conditions under which small-size fishing groups will be successful no matter whether they appropriate stationary resources. C5 and C6 suggest that both monitoring and graduated sanctioning, combined with informal conflict-resolution mechanisms, are sufficient conditions for successful self-governance. Andersson et al.(2014) found that a combination of monitoring and sanctioning has statistically significant positive impact on forest governance. In line with their finding, my result also suggests that the success of fishery systems rely on a coupling of monitoring and sanctioning.

A comparison of C5 with C6 indicates that by-product monitoring (BYMON) is as effective as organized monitoring (OZMON) if both graduated sanctioning (GSANC) and informal conflict-resolution mechanisms (IFCON) are present in small-size groups (LTE100). This implies that biophysical and social infrastructures conducive to monitoring (e.g., small-size mudflat and collective sale) may have an equal effect with resource mobilization for organized monitoring (i.e., monitoring team and hired monitors). In South Korea, an example of the infrastructure contributing to low-cost monitoring is a set of appropriation rules that requires resource users to sale the withdrawn resources collectively and simultaneously at the same marketplace. Such appropriation rules provide each resource user with more chances to find out over-appropriation without additional investments in monitoring activities. A comparison between C6 and C7 signifies that GSANC can be substituted by FCON in small groups if both BYMON and IFCON are present. This suggests that if group size is small, a fall in reputation of rule violators in a formal and open conflict-resolution process can be as effective as graduated sanctions on them.

3.5. Conclusion

Hirschman (1970) argues that the voice option (i.e., articulating critical opinions) can function as an important social feedback mechanism that helps maintain and improve group performance. This is true especially when the exit option (i.e., switching to a better performing group) which facilitates competitions between organizations towards performance improvements is very costly or not available. However, as he pointed out, a question that remains largely unanswered is under what set of institutional and contextual conditions members of an organization can exercise the voice option effectively to enhance group performance. Meanwhile, CPR scholars have explored and reported a variety of institutional and contextual conditions that affect regulatory feedback mechanisms within self-governing groups. They argued that the effectiveness of particular institutions on SESs could vary depending on the biophysical and social contexts in which these rules and norms are operated. There has been, however, little empirical research on how institutional design affects the effectiveness of the voice option and how the fit of voice-promoting institutions with contextual attributes is shaped.

This study attempted to bridge this gap between Hirschman's study on the voice option and the work of CPR scholars on institutional fit by adopting the following four strategies: (1) framing three of Ostrom's DPs (monitoring, graduated sanctioning, and conflict-resolution mechanisms) as voice-promoting institutions; (2) mobilizing CPR studies to select contextual conditions (resource mobility and group size) that help reduce transaction costs of the voice option; (3) operationalizing successful self-governance of local fisheries and coding institutions and social-ecological contexts; and (4) generating hypotheses about the fit of voice-promoting institutions with resource mobility and group size. Framed by this approach, I analyzed empirical data on 30 self-governing fishing groups in South Korea to determine which configurations of voice-promoting institutions and the two contextual conditions are linked to successful self-governance. I used csQCA as a methodological approach for this analysis.

The csQCA results presented five key hypotheses about the fit among voice-promoting institutions, resource stationarity, and group size: (1) if informal conflict-resolution mechanisms led by leaders are absent, then fishing groups will not be successful in self-governance regardless of resource stationarity and group size and the presence of other institutional conditions; (2) in order for fishing groups to be successful only with informal mechanisms for conflict resolution, resource units should be stationary and group size should be small; (3) mobile resources require fishing groups to develop more diverse voice-promoting institutions in comparison to stationary resources; (4) graduated sanctions should be present for successful self-governance of mobile resources whereas the groups appropriating only stationary resources can be successful even if sanctions are not gradually imposed on cheaters; and (5) in small fishing groups, by-product monitoring is as effective as organized monitoring.

A theoretical lesson from this comparative study is that my hypotheses enable us to illustrate how diverse institutional arrangements operate in practice and how this diversity is likely to be linked to their fit with specific biophysical and social contexts.

Such contextual understanding of institutional diversity is critical to policy analysis of what the government should do to foster self-governance beyond one-size-fits-all approach. As the appreciation for self-governance of shared resources increases in the public policy circles, more opportunities will inevitably arise for governments to cultivate self-governance of CPRs. Hence, it is required to produce context-specific knowledge as to why policy outcomes vary across local groups that are exposed to a same policy for self-governance and what aspects of the policy should be improved to achieve its goal.

The csQCA results have policy implications regarding how local institutions of marine resources could be designed to reflect local contextual conditions. For instance, based on C2 and C3, one could suggest that for fishing groups relying on only stationary resources, institutional design should focus on how to motivate group leaders to actively engage in conflict resolution rather than how to establish graduated sanctions. Further, based on C1, one could argue that for small size groups catching mobile resources, policy tools should be focused primarily on how to educate and support group leaders to play a role in settling disputes among their members. However, these policy-relevant insights are based on a limited set of data from 30 South Korean fishing groups and, thus, should be taken with caution. In order to further test the hypotheses associated with these insights, future studies can conduct a statistical analysis of large N cases to estimate the effects of multiplicative interaction terms on successful self-governance of local fisheries. More empirical findings regarding the fit of local institutions with social-ecological contexts will help us develop a clearer map towards a diagnostic approach to commons management. My intent in this paper has been to provide one.

CHAPTER 4

EFFECT OF EXIT ON THE EVOLUTION OF COOPERATION IN PUBLIC GOOD GAMES

4.1. Introduction

Collective action is key to furthering common interests that are difficult to fulfill at an individual level. However, collective action does not always occur sufficiently because of the threat of free riding (Olson 1965). The difficulty of sustaining collective action has led many scholars across disciplines to examine various factors which help solve the free riding problems, such as communication (Ostrom, Walker, and Gardner 1992; Janssen et al. 2010), punishment (Boyd et al. 2003; Sigmund et al. 2010), and group size (Esteban and Ray 2001; McCarthy, Sadoulet, and De Janvry 2001; Yang et al. 2013). Along with the threat of free riding, several studies have been interested in how opportunities to exit from collective-action situations affect cooperation in a system (e.g., Hauert et al., 2007; Janssen, 2008; Orbell et al., 1984; Ye et al., 2011). Members of a tribal society can collect mushrooms instead of participating in a collective hunt (Hauert et al. 2007), and farmers can use privately-owned tubewells instead of shared irrigation canals requiring collective efforts into operation and maintenance (Bardhan and Dayton-Johnson 2002).

Such alternatives outside of collective action arenas become more accessible and diverse due to technological development and social change (e.g., borehole drilling and economic globalization). In competitive markets with a diversity of alternatives, the exit option exercised by dissatisfied consumers is generally expected to help improve the quality of products (Hirschman 1970). This is because widespread use of the exit option motivates firms to compete by improving their products to prevent further loss of customers. This opinion about the positive effect of the exit option in markets is frequently found not only in popular discussions but also in academic writings. However, a consensus on the effect of exit from collective-action situations on cooperation remains elusive.

Several studies to date have found that the exit option can have both positive and negative effects on levels of cooperation. Some studies on the commons focus on the exit options that are empirically detected in several ways (Bardhan and Dayton-Johnson 2002). For instance, resource users can work outside of agriculture or have access to alternative water sources besides shared irrigation canals. The findings from studying the commons in the field suggest that the exit options have the adverse effect on cooperative behavior, such as canal maintenance and rule conformance (Baland and Platteau 1996; Bardhan and Dayton-Johnson 2000). In another set of studies, scholars conducted human-subject and simulation experiments in which subjects (or artificial agents) can exit from social dilemmas to obtain a certain amount of payoff independent of others' choices. Their findings show that the exit option has a positive impact on the evolution of cooperation (Hauert et al. 2007; Janssen 2008), or at least, indicate that the exit option is not quite detrimental to cooperation (Orbell, Schwartz-Shea, and Simmons 1984). However, extant literature provides limited understanding of the several conditions that may determine the effect of exit on cooperation in the long run.

To address this gap, I develop an agent-based model that simulates a set of socioeconomic conditions under which the exit option may either promote or hinder cooperation. In line with the existing studies on the evolution of cooperation (e.g., Boyd and Mathew, 2007; Hauert et al., 2007), the current research defines the exit option as *neither producing a local public good nor consuming the public good produced by others.* Thus, the exit option conceptually differs from defection which is defined in public goods games as consuming the public good produced by others without contributing to the provision of the public good. My model assumes that a society consists of multiple groups to which individual agents belong. Each group produces a local public good in two different situations. In *without-exit* situation, the exit option is not available so that group members can be 1) defectors, 2) nonpunishing cooperators who contribute to a local public good without punishing defectors, and 3) punishing cooperators who contribute to the public good and further punish defectors at their own cost. In addition to these three behavior types, *with-exit* situation allows group members to be exiters who neither produce a local public good nor consume the public good produced by others.

Based on the behavior types above, group members are exposed to a set of socioeconomic conditions. Economic conditions are associated with the payoff structure affecting individual decisions made by group members. First, per capita payoff for cooperators in my model reflects economies of scale which is often neglected in public goods experiments (Boyd and Mathew 2007). For instance, Fehr and Gachter (2002), Gurerk et al. (2006), and Hauert et al. (2007) assume that individual payoff from participating in collective action depends upon the ratio of cooperators to defectors. This means that per capita payoff for cooperators is same both, for example, when there are 10 cooperators, 10 defectors, and 80 exiters in a group, and when there are 40 cooperators, 40 defectors, 20 exiters in the same group. Thus, the assumption fails to capture strong economies of scale observed in many collective action problems, i.e., the more cooperators for infrastructure maintenance, the better the irrigation system works. To reflect economies of scale, my model not only assumes that per capita payoff for cooperators is proportional to their share of total population of the group, but also includes a range of group sizes.

Another economic condition is the exit payoff that affects individual decisions to participate in collective action. One of the three levels (i.e., low, moderate, and high) of the exit payoff is exogenously given to exiters whereas the payoffs for participants in collective action are endogenously changed with population dynamics. Based on the payoff structure, my model assumes that members in a group meet a randomly chosen member and imitate high payoff behaviors, which is in line with the payoff-biased interaction (Boyd et al. 2003; Hauert et al. 2007; Janssen and Rollins 2012). Hence, participants in joint enterprises will likely choose the exit option at a time step when they encounter an exiter whose payoff is higher than their current payoffs. Conversely, exiters will likely participate in joint endeavors when the exit payoff is smaller than the payoffs for participants.

In addition to examining the economic conditions under which individual agents interact to become better off, this study characterizes intergroup interaction as a social process through which more successful groups prevail. I define more successful groups in two ways. First, groups with more cooperators are considered to be more successful in joint enterprises, such as warfare and self-governance of common-pool resources (Boyd et al. 2003). In the remainder of this chapter, the social process through which groups with more cooperators take over groups with fewer cooperators is called the *More-Coop* group interaction

Second, groups with fewer exiters can be recognized as more successful groups especially in response to a decline in participation in collective action. For instance, a society can implement a policy to reduce the number of exiters (conversely, to increase the number of participants in collective action). In South Asia, the North China, Egypt, and Mexico, the use of private tubewells instead of shared canals has been restricted through policy measures, such as creating groundwater zones (Shah et al. 2003; Scott and Shah 2004; Steenbergen 2006). These policies aim to suppress the use of the exit option, thereby regarding groups with fewer exiters as more successful. In the remainder of this chapter, the social process through which groups with fewer exiters take over groups with more exiters is referred to as the *Less-Exit* group interaction.

In the next section, I describe the without- and with-exit situations. The results of cross-situation comparisons are then presented to show how variations in intergroup interactions and exit payoffs shape the effects of exit on the long run average frequency of cooperation. My model results suggest that given the *More-Coop* group interaction, the exit effects vary with the exit payoff and the group size. Under the *Less-Exit* group interaction, however, the exit option always has a negative impact on the evolution of cooperation regardless of the exit payoff and the group size.

4.2. Model Description

To specify the without-exit situation, I used Boyd et al. (2003)'s model which simulated the evolution of cooperation in the absence of exit. Their model also provides insights and references into economies of scale and group interaction, both of which are socioeconomic conditions of interest in the current study. On the other hand, Hauert et al. (2007) lack those two conditions, while considering the exit option as an available individual choice in the face of public goods dilemma. To bridge the gap between the two existing models, this study incorporates the exit option, economies of scale, and group interaction into the with-exit situation.

4.2.1. Without-Exit Situation

My simulation experiments of the without-exit situation were conducted under the assumptions and parameterized conditions described in the model by Boyd et al. (2003). There is a large population consisting of 128 groups of size n. There are three behavioral types in each group: defectors, nonpunishing cooperators, and punishing cooperators. The payoff to a nonpunishing cooperator is $1 + bx - c$, where x is the fraction of nonpunishing and punishing cooperators in the group, and c is the cost of producing a local public good. The term $1 + bx$ represents that a total benefit from the public good is proportional to the fraction of cooperators. The payoff to a defector is $1 + bx - py$, where y is the fraction of punishing cooperators in the group and p is the cost of being punished. The term py indicates that the total cost of being punished increases as the fraction of punishing cooperators increases. This is because each defector is punished by every single punisher. The payoff to a punishing cooperator is $1 + bx - c - k(1 - x)$, where k is the cost of punishing each defector. The term $k(1 - x)$ implies that the total cost of punishing is in proportional to the fraction of defectors because each punisher punishes every single defector.

Initially one group has only punishing cooperators and the remaining 127 groups consist of all defectors. Each time step comprises five sequential stages. First, nonpunishing and punishing cooperators contribute to producing a local public good with probability $1 - e$ and defect with probability e. Defectors do not make such an error, and thus defect at all time. Second, punishing cooperators reduce the payoff of each member who defected during the first stage. After the second stage, group members imitate higher payoff individuals. Members in a group encounter another member from their own group with probability $1 - m$ and a member from another randomly chosen group with probability m. A member i who encounters a member j imitates j with probability $\frac{w_j}{(w_j+w_i)}$, where w_q is the payoff of member q in the game, including the costs of punishing and being punished. This individual imitation leads to not only the spread of higher payoff behaviors within group, but also diffusion of the behaviors between groups with probability m. During the fourth stage, group selection occurs through the *More-Coop* group interaction. The process of the *More-Coop* group interaction is as follows. Each group is randomly paired with one of the other groups with probability s. Their interaction results in one group taking over another group. The probability that group i takes over group j is $0.5\{1 + (x_i - x_j)\}$, where x_g is the frequency of nonpunishing and punishing cooperators in group g. This means that the group with more cooperators is more likely to take over another group with fewer cooperators. As a result, cooperation is the sole target of the resulting cultural group selection process. Finally, there is a small change of mutation for each member with probability μ (i.e., defectors flip to nonpunishing cooperators).

4.2.2. With-Exit Situation

The with-exit situation is designed to reflect the situation in which groups are subjected to social changes that may decrease the participation in collective action. For example, private infrastructures (i.e., tubewells) can be used thanks to technological development and nonfarm employment becomes attractive due to economic globalization. One of the biggest differences between the without- and with-exit situation is the payoff function for punishing cooperators. The presence of the exit option changes the punisher's payoff function from $1 + bx - c - k(1 - x)$, where x is the fraction of nonpunishing and punishing cooperators, to $1 + bx - c - k(1 - x - z)$, where z is the fraction of extiers. This is because the total cost of punishing is determined by the fraction of defectors who are neither cooperators nor exiters. The payoff function for nonpunishing cooperators remains the same as it was in the without-exit situation: $1 + bx - c$. The payoff function for defectors also remains the same as it was: $1 + bx - py$, where y is the fraction of punishing cooperators. In line with Hauert et al. (2007), the exit payoff (Ω) is exogenously given to group members while the payoffs for participants in collective action vary with endogenous population dynamics. Because the amount of exit payoff is critical to individual decisions to participate in collective action, I gave exiters different payoffs ($\Omega = 0.800, 0.925, and\ 1.050$) to examine effects of the exit payoff on the frequency of cooperation. Once one of the exit payoffs is given to a simulation, it is constant throughout the simulation. Such exit payoffs are set to be the same as the payoff that nonpunishing cooperators obtain (1) when no members within a group contribute to local public goods, (2) when 25% do, and (3) when 50% do.

As in the without-exit situation, one group consists of all punishing cooperators and the other 127 groups have only defectors. The five steps described in the without-exit situation also are taken in each time period: contribution with erroneous defection, punishment on defection, individual imitation, group interaction, and mutation. Note that an initial introduction of the exit option to group members is attributed to mutation, i.e., participants in collective action flips to exiters with probability μ.

Among such five stages, individual imitation is a critical mechanism that helps non-exiting members (that is, participants in joint enterprises) to gain the information about the exit payoff. Both defectors and cooperators can encounter exiters, thereby updating the exit payoff that affects the probability of their exiting collective-action situations. The probability of exit follows the formula which is already provided to identify the process of individual imitation in the without-exit situation, $\frac{w_j}{(w_j+w_i)}$, where w_q is the payoff of member q. After individual imitation stage, I apply either the *More-Coop* or the *Less-Exit* group interaction to a simulation. Like the *More-Coop*, the *Less-Exit* starts with having groups paired at random and with probability s. However, cultural group selection between the paired groups does not occur toward increasing the number of cooperators, but toward reducing the number of exiters. The probability that group i takes over group j is $0.5\{1 + (z_j - z_i)\}$, where z_g is the frequency of exiters in group g. This means that the group with fewer exiters is more likely to take over another group with more exiters.

4.3. Model Analysis

In this section, I compare the without-exit and with-exit situations to investigate the effects of exit on cooperation in the long run. To do so, three hypothetical scenarios were simulated (see Table 4.1). Following Boyd et al. (2003), the baseline scenario is characterized by the *More-Coop* group interaction in the absence of the exit option. In Scenario 1 and 2 where the exit option is available, three levels of the exit payoff are exogenously given to exiters and two different types of group interactions occur. A comparison between the baseline and the latter two scenarios helps us to explore under what set of socioeconomic conditions the exit option contributes to enhancing the long run average frequency of cooperative behaviors.

Table 4.1. Three scenarios simulated.

<table>
<tr><th>Model</th><th>Scenario</th><th>Exit option</th><th>Group interaction</th><th>Exit payoff</th></tr>
<tr><td>Without-exit situation</td><td>Baseline</td><td>Absence</td><td>More-Coop</td><td>N/A</td></tr>
<tr><td rowspan="2">With-exit situation</td><td>Scenario 1</td><td rowspan="2">Presence</td><td>More-Coop</td><td rowspan="2">0.800, 0.925, and 1.050</td></tr>
<tr><td>Scenario 2</td><td>Less-Exit</td></tr>
</table>

For a range of group sizes (n), each scenario was simulated using the parameter values that Boyd et al. (2003) chose to capture cultural evolution in small-scale societies (see Table 4.2). I also followed Boyd et al. (2003) to identify a span of simulation time (time period = 1 year) and a way of calculating the long run average frequency of cooperation. Each scenario was run for 2,000 time periods. Considering an initialization period, I report the long run average frequencies of cooperation, defection, and exit over the last 1,000 time periods of 100 simulations. These long run results of each scenario are plotted in Fig. 4.1 and 4.2.

Table 4.2. Default parameter values.

Parameter	Description	Default value
N	Number of groups	128 (source: Boyd et al. 2003)
n	Number of agents in each group	Varying (20 to 120)
b	Benefit if everyone cooperates	0.5 (source: Boyd et al. 2003)
c	Cost of cooperation	0.2 (source: Boyd et al. 2003)
p	Cost of being punished	0.8 (source: Boyd et al. 2003)
k	Cost of punishing	0.2 (source: Boyd et al. 2003)
m	Rate of mixing between groups (for individual imitation)	0.01 (source: Boyd et al. 2003)
μ	Mutation rate	0.01 (source: Boyd et al. 2003)
s	Rate of group pairing (for cultural group selection)	0.015 (source: Boyd et al. 2003)
e	Erroneous defection rate	0.02 (source: Boyd et al. 2003)
Ω	Exit payoff	Varying (0.800, 0.925, and 1.050)

4.3.1. Analysis I: Effect of Exit under the *More-Coop*

In this subsection, the long run results of the baseline scenario (without the exit option) are compared to those of Scenario 1 in which the exit option is available and the *More-Coop* group interaction occurs. The dotted lines in Fig. 4.1 represent the results of the baseline scenario, such as the long run average levels of cooperation, defection, and exit. Three solid lines in each panel of Fig. 4.1 show how the long run results of Scenario 1 change as the exit payoff increases.

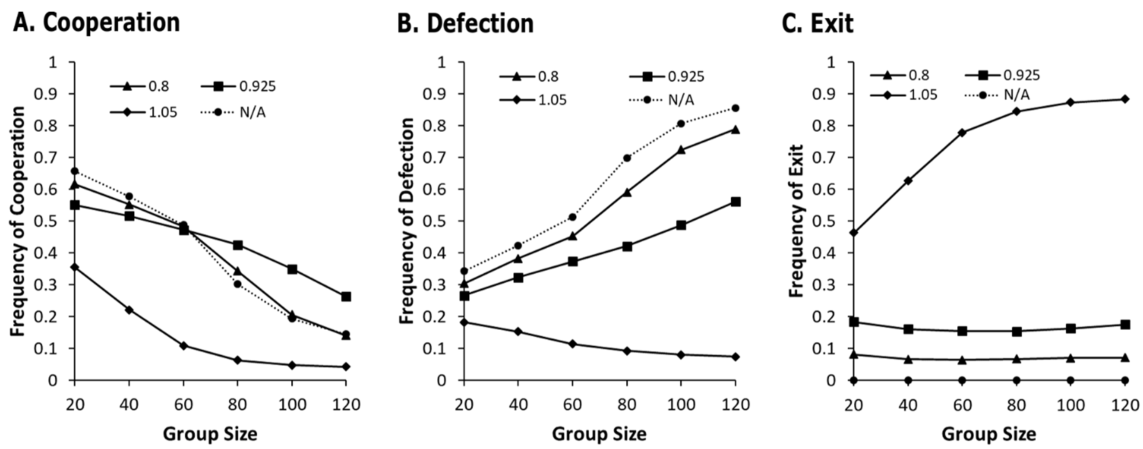

Figure 4.1. The long run average frequency under the *More-Coop*. (A) Cooperation (i.e., the sum of the frequencies of nonpunishing and punishing cooperators); (B) Defection; and (C) Exit. In panels (A), (B), and (C), the dotted lines indicate the long run results in the absence of exit, and the solid lines in the presence of exit. Three types of markers (triangle, square, and diamond) of the solid lines represent the low exit payoff (0.8), the moderate (0.925), and the high (1.05), respectively.

A major finding from the first analysis is that exit payoff has nonlinear effects on the long run average frequency of cooperation. Fig. 4.1A shows that compared to the absence of exit (dotted line), the low exit payoff (triangle marker) makes little or no difference for the long run average of cooperation across group sizes. The low exit payoff contributes to reducing the frequency of defection (Fig. 4.1B). The decreased defection coincides with an increase in exiters (Fig. 4.1C) so that the frequency of cooperation does not change significantly. The high exit payoff (diamond marker) has an obviously negative effect on cooperation across group sizes, while reducing the number of defectors remarkably (Fig. 4.1B). The reason why the decreased defection does not lead to an increase in cooperation is that the exit payoff is high enough for a great number of members to prefer exiting to participating in collective action. Such a great deal of exit is shown in Fig. 4.1C.

The most interesting finding is that the moderate exit payoff has an asymmetric effect on cooperation across group sizes. To put it another way, as shown in Fig. 4.1A, the moderate exit payoff (square marker) affects levels of cooperation negatively for small-size groups (e.g., $n = 20, 40$) but positively for mid- and large-size groups (e.g., $n = 80, 100, and\ 120$). As the group size gets larger, the frequency of defection at the moderate level of exit payoff becomes lower than that in the absence of exit. This is represented by an increase in the vertical distance between square and circle markers in Fig. 4.1B. However, the frequency of exit is almost constant (approximately 0.2) regardless of the group size (Fig. 4.1C). Hence, these trends help us to arithmetically understand that the frequencies of cooperation for mid- and large-size groups are higher at the moderate level of exit payoff than in the absence of exit. This result suggests that given the *More-Coop* group interaction, the moderate exit payoff becomes more effective in enhancing levels of cooperation as the group size gets larger.

4.3.2. Analysis II: Effect of Exit under the *Less-Exit*

In a similar way, the long run results of the baseline scenario (without exit) are compared to those of Scenario 2 in which the exit option is available and the *Less-Exit* group interaction occurs. All the socioeconomic conditions used in my second analysis, except the type of group interaction, are the same as in the first analysis. Such a *ceteris paribus* setting helps us to better understand how those different types of group interactions affect the long run average frequencies of cooperation, defection, and exit. Fig. 4.2 summarizes the long run results of Scenario 2.

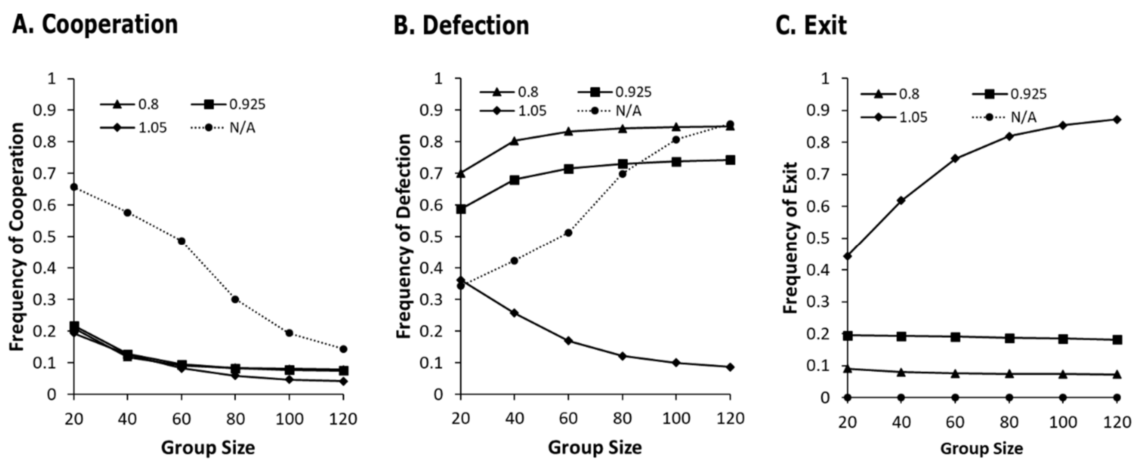

Figure 4.2. The long run average frequency under the *Less-Exit*. (A) Cooperation (i.e., the sum of the frequencies of nonpunishing and punishing cooperators); (B) Defection; and (C) Exit. In panels (A), (B), and (C), the dotted lines indicate the long run results in the absence of exit, and the solid lines in the presence of exit. Three types of markers (triangle, square, and diamond) of the solid lines represent the low exit payoff (0.8), the moderate (0.925), and the high (1.05), respectively.

Fig. 4.2A shows that regardless of the exit payoff and the group size, the frequency of cooperation falls precipitously under the *Less-Exit* group interaction in comparison to the absence of exit. This is the most salient difference between the results of the different types of group interactions: a consistently negative effect of exit on cooperation under the *Less-Exit* vs. nonlinear effects of exit under the *More-Coop*. However, a comparison of Fig. 4.2C with Fig. 4.1C demonstrates that those two types of group interactions make little or no difference in the frequency of exit across exit payoffs.

This means that compared to the *More-Coop*, the *Less-Exit* is not more effective in achieving its original goal of reducing the number of exiters. Instead, the *Less-Exit* contributes to increasing the frequency of defection substantially at the low and moderate levels of exit payoff (Fig. 4.2B) while the frequency of defection falls dramatically at the high level of exit payoff.

These contrasting trends in the frequency of defection help identify two different paths toward the commonly observed, negative effect of exit on cooperation across the exit payoffs in Fig. 4.2A. One of the paths presents the possibility that a substantial drop in levels of cooperation is influenced by defection rather than exit. For instance, the low and moderate exit payoffs do not generate a great number of exiters (Fig. 4.2C), but instead lead to a significant number of defectors (Fig. 4.2B). These cases indicate a defection-driven pathway to the negative effect of exit on cooperation. Another pathway is driven by exiters rather than defectors. As the group size gets larger in Fig. 4.2C, the high exit payoff is more likely to incentivize group members to exit. Thus, the frequency of exit increases to approximately 0.9. Such a considerable amount of exit results in the dramatic fall in both cooperation and defection.

4.4. Discussion

In Analysis I, I observed that the exit option has not only nonlinear effects on cooperation across exit payoffs, but also asymmetric effects on cooperation across group sizes at the moderate level of exit payoff. This section aims to provide valuable insights into what evolutionary forces come into play jointly to shape those nonlinear and asymmetric effects. To do so, three evolutionary forces need to be identified that affect levels of cooperation in the presence of exit. Force 1 and 2 are associated with the exit option and derive from payoff biased imitation at the individual level, while Force 3 comes from the *More-Coop* group interaction. Note that the three forces described below are not an exhaustive list of evolutionary forces. However, those three forces are related to the exit option so that they can help us to better understand why the effects of exit on cooperation change under different combinations of socioeconomic conditions.

- Force 1: The availability of the exit option could lead defectors to not participate in collective action. To the extent this is the case, the cost of punishing, which is proportional to the number of defectors, goes down. Such a payoff advantage of punishing cooperators will likely increase the number of punishing cooperators. Hence, an additional decrease in defectors could occur.
- Force 2: The availability of the exit option could lead punishing cooperators to not participate in collective action. To the extent this is the case, the cost of being punished, which is proportional to the number of punishing cooperators, goes down. Such a payoff advantage of defectors will likely increase the number of defectors, and thus leads to the payoff disadvantage of punishing cooperators. Hence, an additional decrease in punishing cooperators could occur.
- Force 3: The *More-Coop* group interaction contributes to the spread of punishing cooperators which is likely to decrease the number of defectors.

The simulation results of the low exit payoff (see triangle markers in Fig. 4.1) show that the presence of exit has little or no effect on levels of cooperation in comparison to the absence of exit. This can be caused by underactivation of both Force 1 to decrease the number of defectors and Force 2 to reduce the number of punishing cooperators. If the exit payoff is too small, it rarely incentivizes defectors and punishing cooperators to be exiters. Thus, Force 1 and 2 cannot be activated sufficiently. However, Force 3 which also exists in the presence of exit still comes into play at the low level of exit payoff. Hence, the results of cooperative evolution at the low level of exit payoff become very similar to those in the absence of exit.

The simulation results of the high exit payoff (see diamond makers in Fig. 4.1) report a dramatic fall in levels of cooperation in comparison to the absence of exit. This can be explained by overactivation of the two forces, Force 1 and 2. If the exit payoff is too high, both defectors and punishing cooperators will likely exit very quickly. Thus, Force 1 and Force 2 are extremely activated so that a great deal of exit can take place before levels of cooperation become high enough to incentivize group members to participate in collective action. Because the current exiters include those who were cooperators in the past, it is obvious that the huge tendency to exit leads to a decrease in the payoffs for participants (including cooperators and defectors) in collective action. Given the payoff disadvantage of participants, Force 3 is not strong enough to suppress such a great deal of exit which is attributed to individual payoff-biased imitation. Therefore, the significant drop in cooperation occurs at the high level of exit payoff.

Unlike the low and high exit payoffs above, the simulation results of the moderate exit payoff indicate that the direction of the exit effect is influenced by group size. For example, levels of cooperation in small-size groups (e.g., $n = 20$) become lower at the moderate level of exit payoff than those in the absence of exit. The negative effect of exit on cooperation is represented by a black bar at the bottom of Fig. 4.3A. However, levels of cooperation in large-size groups (e.g., $n = 120$) become higher at the moderate level of exit payoff than those in the absence of exit. The positive exit effect is shown as a white bar at the bottom of Fig. 4.3A, and a gray bar indicates that there is little or no change in levels of cooperation in mid-size groups (e.g., $n = 60$).

The variation of the exit effect with group size (namely, asymmetric effects of exit) can also be accounted for by the three identified forces above. As shown in Fig. 4.3A, there must be exiters regardless of the group size and the frequency of exit is similar across group sizes. Hence, a key question that should be addressed to explain the asymmetric effects is which behavior is decreased or increased by the presence of exit between defection and cooperation. To address the question, it is noteworthy that Force 1 and 3 contributes to reducing the number of defectors, whereas Force 2 helps decrease the number of punishing cooperators.

In the case of $n = 20$ (black bars), a decrease in both defection and cooperation is reported. The directions and lengths of the defection and cooperation bars implies that an aggregate of Force 1 and 3 is almost balanced against Force 2. The case of $n = 60$ (gray bars) indicates that an aggregate of Force 1 and 3 is stronger than Force 2, but not so much as to overwhelm Force 2 . This means that the exit option is successful in suppressing the spread of defectors to some extent while being ineffective in enhancing levels of cooperation. In the case of $n = 120$ (white bars), a significant decrease in defection is accompanied by an increase in cooperation. This might be attributed to an override of Force 2 by an aggregate of Force 1 and 3; in other words, the aggregated force to reduce the number of defectors is so strong that the cost of punishing can decrease sufficiently to contribute to the spread of punishing cooperators despite Force 2 aimed at reducing the number of punishing cooperators.

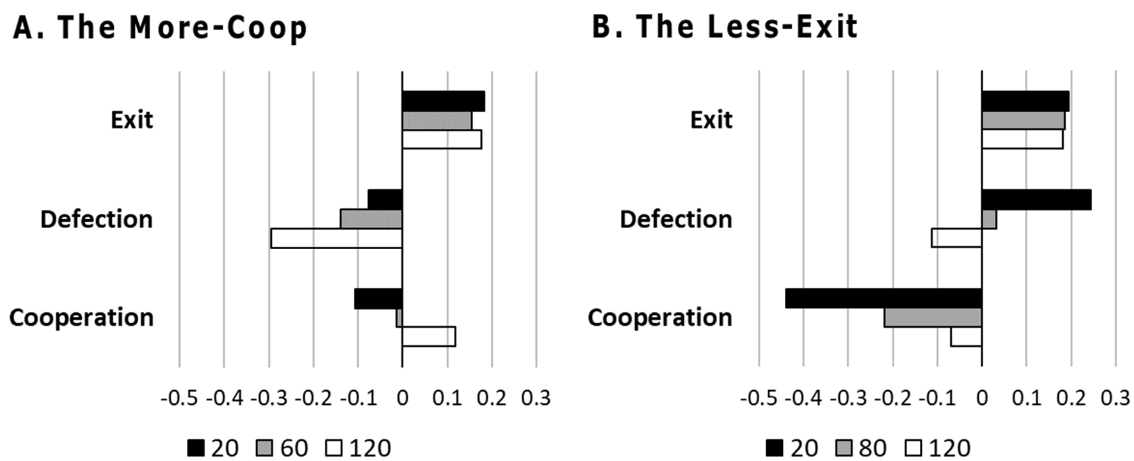

Figure 4.3. Difference in the long run average frequency. (A) The *More-Coop* group interaction in the with-exit situation; and (B) The *Less-Exit* group interaction in the with-exit situation. Given the moderate exit payoff (0.925), each bar represents the difference calculated by subtracting the frequency of each behavior in the absence of exit from that in the presence of exit. Three different colors of bars represent group sizes.

In Analysis II, I found that the *Less-Exit* group interaction shapes a detrimental effect of exit on cooperation. The *Less-Exit* leads a group with fewer exiters to take over another group with more exiters. This implies that even if a group with fewer exiters has more defectors than another group with more exiters, the former takes over the latter. Hence, the *Less-Exit* enables defectors to diffuse across groups. The tendency toward an increase in defection is likely to be strengthen especially during the early stages of my simulation. This is because the current model is initially dominated by defectors, i.e., 127 groups consisting of all defectors and only one group with all punishing cooperators. Therefore, a new version of Force 3 between groups should be identified instead of the old version of Force 3 which the *More-Coop* drives to contribute to decreasing the number of defectors.

- Force 3: The *Less-Exit* group interaction contributes to the spread of defectors which is likely to decrease the number of cooperators.

Force 1 and 2 still come into play in the way they did under the *More-Coop* because both forces do not originate from group interaction but from payoff biased imitation at the individual level. Note that Force 2 and 3 contribute to decreasing the number of cooperators, whereas Force 1 helps reduce the number of defectors.

In Fig. 4.3B, the case of $n = 20$ (black bars) report that a substantial increase in defection co-occur with a precipitous fall in cooperation. This could occur when an aggregate of Force 2 and 3 overwhelms Force 1. To put it another way, the aggregated force to reduce the number of punishing cooperators is strong enough to considerably decrease the cost of being punished. As a result, the speed with which the aggregated force increases the number of defectors is greater than the speed with which Force 1 reduces the number of defectors. Similarly, the case of $n = 80$ (gray bars) results in both increased defection and decreased cooperation, while the variations are even smaller than those in the case of $n = 20$. This could occur when an aggregate of Force 2 and 3 slightly overwhelms Force 1. Lastly, an interesting finding from the case of $n = 120$ (white bars) is a decrease in defection which differs from the former two cases (i.e., $n = 20, 80$). The simultaneous decrease in both defection and cooperation indicate that Force 1 is not overwhelmed by an aggregate of Force 2 and 3 but becomes balanced against the aggregated force.

4.5. Conclusion

Hauert et al. (2007) argues that “if individuals have the option to stand aside and abstain from the joint endeavor, this paves the way for the emergence and establishment of cooperative behavior” (Hauert et al. 2007, 1905). Their argument suggests the possibility that the prosocial norm at the group level can emerge from the individual imitation of higher payoff behaviors. In the current study, I took their model a further step by modeling cultural group selection characterized as the *More-Coop* and the *Less-Exit* group interaction. To investigate how these interactions between groups shape the effect of exit on cooperation, the results of the without-exit situation (baseline scenario) were compared to those of the *More-Coop* (Scenario 1) and the *Less-Exit* (Scenario 2), respectively.

Such comparisons report that given the *More-Coop*, the exit option can have a neutral, negative or positive effect on the long run average frequency of cooperation. The directions of the exit effects vary with the exit payoff and the group size: a neutral effect is observed at the low level of exit payoff, a negative effect at the high level of exit payoff, and either a positive or negative effect at the moderate level of exit payoff for mid- and large-size groups. However, the *Less-Exit* was found to lead to a precipitous fall in the long run average frequency of cooperation, regardless of changes in exit payoff and group size. To explain how group interaction and exit payoff jointly shape the exit effect, this study identified three types of evolutionary forces and explored how those forces come into play: two exit-related forces driven by individual payoff-biased imitation, and one force driven by group interaction. A less from this study is that social changes allowing for the exit option are not always detrimental or beneficial to the evolution of cooperation. What matters to the evolution of cooperation is the amount of exit payoff as well as types of interactions between groups.

Future studies may consider an alternative model of local public goods with an extended conception of exit. Like Hauert et al. (2007), the current study depends on a narrow conception of exit which is predicated on the assumption that exiters cannot contribute to producing local public goods. For instance, if an individual chooses to personally harvest mushrooms, he or she is unable to participate in collective hunting during the harvest time. Such a narrowly conceptualized exit makes sense particularly when a direct investment of time and labor is required to provide the public goods. However, evidence from empirical studies on urban-to-rural migration suggests that part of remittance flows is invested in shared infrastructure (e.g., shrimp farming and education) in the receiving areas (Adger et al. 2002). The use of remittance income indicates that those who leave resource-dependent communities to seek new economic opportunities can also contribute to providing local public goods in places of migrant origination. Modeling the extended conception of exit should be accompanied by investigating at least two parameters, such as a ratio of remittance to non-farm income (i.e., exit payoff) and a ratio of contribution to local public goods to the received remittance income.

CHAPTER 5

CONCLUSION

5.1. Summary of the Research Findings

Social-ecological systems (SESs) are often subject to human-driven internal stresses that cause a decline in system performance. Examples of internal stresses are bureaucratic behaviors (e.g., shirking and slack), violation of rules for self-governing common-pool resources, and free riding problems around collective action. The aim of this thesis is to explore what kind of internal stress is problematic in a SES and how to cope with the stress to help sustain the SES. I tackled these questions of social feedback mechanisms by mobilizing Hirschman (1970)'s *exit* and *voice* that represent individual responses to decline in system performance. In the broadest sense, the exit option means any response to escape from an objectionable state of affairs, and the voice option is defined as any attempt to stay put and improve the state. A central challenge for the use of exit and voice as social feedback mechanisms is to explore under what conditions the two options work effectively to sustain SESs. Using multi-method approach, this thesis addresses the challenge through three studies of different types of SESs (irrigation and fishery systems) and public goods dilemmas which are often observed in SESs.

In Chapter 2, I developed a stylized dynamic model of government-managed irrigation systems where both the exit and voice options are available to farmers in response to decline in public infrastructures (e.g., shared canals). The exit option is utilizing privately-owned tubewells, and the voice option is expressing their dissatisfactions and demands. The exit option can put monetary loss on an irrigation bureau by reducing the revenues from irrigation service fees. So does the voice option by inflicting direct costs on the bureau in charge of dealing with the issues raised by farmers. Using this model of farmer-agency interactions, I examined under what conditions the interplay of exit and voice can positively affect the long-term dynamics of system performance. The conditions of interest in this study are represented by two characteristics of bureaucratic reactions to monetary losses caused by the exit and voice options: sensitivity characterized as the minimum amount of monetary loss beyond which O&M efforts start to be made by the agency; durability characterized as the maximum amount of monetary loss below which the efforts are sustained in the face of increasing losses.

The model results suggest that the interplay of exit and voice can work as social feedback mechanisms not only for improving public infrastructures if the agency is highly sensitive to monetary losses, but also for making the infrastructures more resilient to an external shock if the agency is highly durable to monetary losses. I also explored how the silence option – neither exercising the exit option nor the voice option – shapes the effects of social feedback mechanisms on system dynamics. The model results show that silent farmers impede a further improvement in government-managed infrastructure, while contributing to a dramatic improvement in the infrastructure in a limited number of cases.

In Chapter 3, I conducted a qualitative comparative analysis (QCA) of 30 self-governing fishing groups in South Korea to understand under what conditions the voice option will work effectively as a social feedback mechanism for self-controlling rule infractions. Specifically, I considered Ostrom's Design Principle 4 (monitoring), 5 (graduated sanctions), and 6 (conflict-resolution mechanisms) as voice-promoting institutional conditions. These institutional rules can help make members' voice heard about who violated rules, what level of sanction is appropriate for the offender, and how to coordinate various interpretations of what constitutes rule infractions. In addition to such voice-promoting institutions, I considered the attributes of resource mobility and group size as social-ecological conditions that affect transaction costs of the voice option for monitoring and enforcement.

The QCA results report empirical hypotheses about configurations of institutional and social-ecological conditions linked to successful functioning of the voice option. The hypotheses suggest that 1) if the leader-led informal mechanism for conflict resolution is absent, then fishing groups will not be successful regardless of resource mobility and group size; 2) even if rules for monitoring and graduated sanctions are not in use, small groups appropriating only stationary resources will be with the informal mechanisms for conflict resolution; and 3) graduated sanctions should be present for success in managing mobile resources while the groups appropriating only stationary resources will be successful even if graduated sanctions are absent.

In Chapter 4, I developed an agent-based model of public good games where individual agents may exercise the exit option which is defined as neither producing a local public good nor consuming the public good produced by others. Using the simulation model, I examined under what set of socioeconomic conditions the exit option will work effectively as a social feedback mechanism for enhancing levels of cooperation under the threat of free riding. A key economic condition is the exit payoff that affects individual decisions about whether to participate in collective action situations. In each simulation, agents who exercise the exit option can obtain one of the three levels of exit payoff (i.e., high, medium, and low) independent of others' choices, whereas the payoff for participants (e.g., defectors and cooperators) in public good games vary with the fraction of cooperators over time. Based on the payoff structure, each agent in a group encounters a randomly chosen member from the same group or from other groups to imitate higher payoff behaviors. As a social condition, I considered two types of group interactions resulting in one group taking over another group. The *More-Coop* group interaction leads a group with more cooperators to take over another group with fewer cooperators. In response to a decline in participation in collective action (conversely, an increase in the number of exiters), the *Less-Exit* group interaction leads a group with fewer exiters to take over another group with more exiters.

My model results suggest that regardless of the exit payoff and the group size, the exit option has a detrimental effect on the evolution of cooperation under the *Less-Exit* group interaction. Given the More-Coop group interaction, however, the effects of exit on cooperation can become neutral, negative, or positive as the exit payoff and the group size vary. For instance, the exit option is found to be a contributor to enhancing levels of cooperation for mid- and large-size groups with the exit payoff moderate.

5.2. Synthesis: Governing Social Feedback Processes

The theoretical importance of social feedback mechanisms is found in the dialectical development of ideas on human-environment interactions. The first stage (*thesis*) of the dialectical process was dominated by command-and-control approach to environmental problems including resource depletion and pollution. However, top-down resource management policy from the 1970s to the 1990s had failed because they depended on a naïve view of ecosystem dynamics (Anderies 2014). The "pathology of command-and-control resource and environmental management" (Holling and Meffe 1996) opened the door to the next stage (*antithesis*). In response to failed top-down policy, the concept of ecological resilience emerged that views an ecological system as a self-organizing system and human actions as external to the system (Anderies 2014; Folke 2006). Such an ecological resilience perspective excludes the interdependencies between ecosystem change and social dynamics (Folke 2006), and often regards human activities as perturbations of an ecological system (Janssen and Anderies 2007).

To resolve the conflict between the first idea and the second (*thesis* and *antithesis*), the social-ecological system perspective (*synthesis*) have developed and flourished which emphasizes that human choices and consciously designed components are critical to coping with perturbations (McGinnis and Ostrom 2014; Janssen and Anderies 2007). A key research challenge for sustaining social-ecological systems is to spell out the specifics of the feedbacks of the interlinked social-ecological systems (Folke 2006).

With a focus on social feedback mechanisms, my attempt to address this challenge started with identifying human choices and consciously designed components of social-ecological systems. I used Hirschman (1970)'s exit-voice model to identify individual choices in response to decline in well-defined system performances, such as improvements in government-managed irrigation infrastructure (Chapter 2), successful self-governance of local fisheries (Chapter 3), and the long run average frequency of cooperation for the provision of local public goods (Chapter 4). Human components, which are consciously designed to cope with perturbations, were identified as physical infrastructure (Chapter 2), institutions (Chapter 3), and more generally, public goods (Chapter 4). In addition, my attempt to study social feedback mechanisms was extended to explore a variety of conditions under which exit and/or voice can contribute to achieving well-defined performance objectives of SESs.

This dissertation has two major policy implications regarding how to govern social feedback processes for coping with internal stresses that may be amplified due to external shocks to social-ecological systems, such as climate change and economic globalization. First, institutionalizing individual freedom of exit and voice helps mitigate human-driven internal stresses, thereby enhancing system performances. The exit and voice options are fundamentally different from the command-and-control approach because both options are voluntarily chosen by resource users themselves in the face of bureaucratic shirking, rule infraction, and free riding.

Chapter 2 suggests that a combination of vertical voice (voicing to public authorities) and exit can be effective in improving government-managed irrigation systems. In Chapter 3, I argued that horizontal voice (voicing to members of a group) plays a role in self-controlling rule infractions in self-governed fishery systems. Chapter 4 shows that exit can contribute to reducing the number of free riders in public goods games. These results demonstrate the potentiality of exit and voice for social feedback mechanisms which do not depend on top-down resource management policy but on individual choices.

Second, policy makers should be able to reflect on the significance of contextual conditions that affect the effectiveness of exit and voice in improving system performances. I examined a variety of conditions under which the exit and voice options function properly as social feedback mechanisms for coping with internal stresses that cause a decline in system performances: political context (bureaucratic behaviors) in Chapter 2, biophysical and social contexts (resource mobility and group size) in Chapter 3, and socioeconomic contexts (exit payoff and intergroup interaction) in Chapter 4.

Chapter 2 shows that different patterns of bureaucratic reactions to farmers' exit and voice affect the long-run quality of public infrastructure, and thus they generate multiple types of irrigation regime. Chapter 3 suggests that the attributes of resource mobility and group size play a significant role in shaping different configurations of voice-promoting institutions – Ostorm's DPs for rule enforcement – that are likely to lead to successful self-governance of local fisheries. Chapter 4 argues that levels of exit payoff, combined with types of intergroup interactions, affect the direction and degree of the effect of exit on the long run average frequency of cooperation. A key message from these findings is that the exit and voice options should be institutionalized in accordance with a set of contextual conditions in which social-ecological systems are embedded. Contexts matter in governing social feedback mechanisms.

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APPENDIX A

SUPPORTING INFORMATION FOR CHAPTER 3

A.1. Fishing group information

Table A.1. Group names and IDs.

Fishing Groups		
Group ID	Group Name	Province/City
1	Jong-Hyun (JH)	GYEONGGI-DO
2	Ye-Dang (YD): Inland fishery	CHUNGCHEONGNAM-DO
3	BagMee-Ree (BMR)	GYEONGGI-DO
4	NamBoo (NB)	GYEONGSANGNAM-DO
5	Mae-Hyang 2 (MH2)	GYEONGGI-DO
6	Seok-Cheon (SCH)	GYEONGGI-DO
7	Tan-Do (TD)	GYEONGGI-DO
8	Jook-Byun (JB)	GYEONGSANGBUK-DO
9	MooChang-Po (MCP)	CHUNGCHEONGNAM-DO
10	JangSa-Dong (JSD)	GANGWON-DO
11	Do-Seong (DS)	CHUNGCHEONGNAM-DO
12	Joong-Wang (JW)	CHUNGCHEONGNAM-DO
13	Jang-Hwan (JH)	JEOLLANAM-DO
14	Shin-Wol (SW)	JEOLLANAM-DO
15	Duck-Gyo (DG)	INCHEON METROPOLITAN CITY
16	MahSee-Ahn (MSA)	INCHEON METROPOLITAN CITY
17	Do-Hwang (DH)	CHUNGCHEONGNAM-DO
18	Goong-Hang (GH)	JEOLLABUK-DO
19	JangJa-Do (JJD)	JEOLLABUK-DO
20	ShinSee-Do (SSD)	JEOLLABUK-DO
21	Dong-Ree (DR)	BUSAN METROPOLITAN CITY
22	MeeDo-Duck (MDD)	GYEONGSANGNAM-DO
23	Sun-Doo (SD)	INCHEON METROPOLITAN CITY
24	Heung-Wang (HW)	INCHEON METROPOLITAN CITY
25	ShinJean-Hang (SJ)	CHUNGCHEONGNAM-DO
26	Pah-Do (PD)	CHUNGCHEONGNAM-DO
27	ChaeSeock-Po (CSP)	CHUNGCHEONGNAM-DO
28	Oe-Ong-Chee (OOC)	GANGWON-DO
29	Dae-Po (DP)	GANGWON-DO
30	Mahn-Wol (MW)	JEOLLABUK-DO

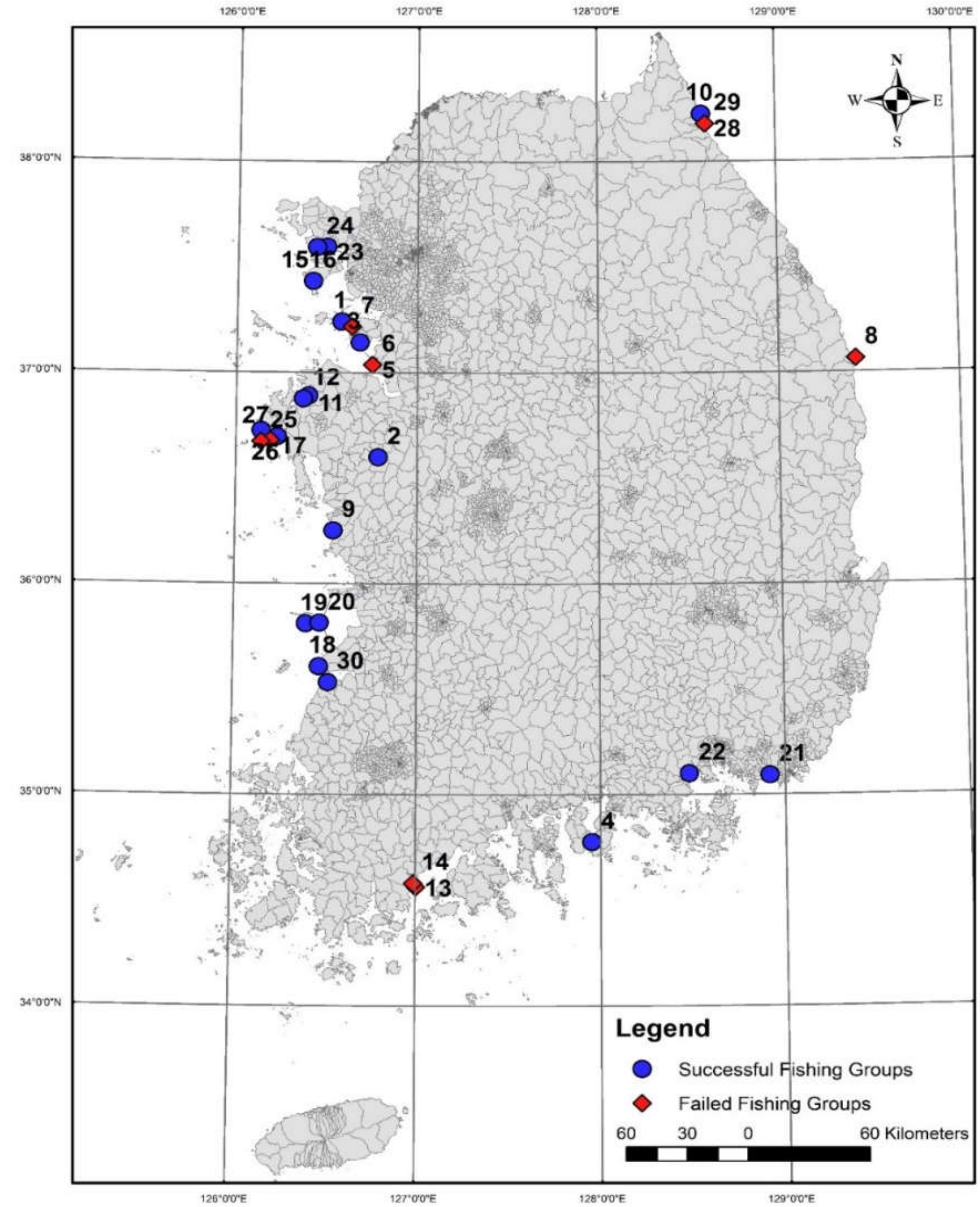

Figure A.1. Locations of successful and not-successful groups. South Korea is bounded on three sides (East, West, and South) by the sea. 30 groups are in almost every administrative district facing the sea. Blue circles represent successful fishing groups, and red diamonds represent not-successful fishing groups.

A.2. Ten outcome variables, seven conditions, and intercoder reliability

Table A.2. Coding questions, ten outcome variables, and overall assessment.

Outcome variables	Coding Questions
1. BEGBLNC	For natural resources at the beginning of this period, the balance between the quantity of units withdrawn and the number of units available is*: (1) Extreme shortage; (2) Moderate shortage; (1,2) Shortage; (3) Apparently balanced; (4) Moderately abundant; (5) Quite abundant; (4,5) Abundant; (-l) MIC; (-2) NA *In fisheries and other biological system, this is the maximum sustainable number of resource units
2. ENDBLNC	For natural resources at the end of this period, the balance between the quantity of units withdrawn and the number of units available is*: (1) Extreme shortage; (2) Moderate shortage; (1,2) Shortage; (3) Apparently balanced; (4) Moderately abundant; (5) Quite abundant; (4,5) Abundant; (-l) MIC; (-2) NA *In fisheries and other biological system, this is the maximum sustainable number of resource units
3. NATINFRACOND	During this period, has the condition of the natural infrastructure improved, remained the same, or worsened due to the appropriators' behavior? (1) Improved; (2) Remained the same; (3) Worsen; (-1) MIC
4. RULEFOLLA	Characterize the usual behavior of the appropriators with respect to local operational level rules-in-use related to the appropriation process from this resource in years other than extreme shortage: (1) Almost all members follow the rules (2) Most members follow the rules (1,2) More than half of the members follow the rules (3) About half of the members follow the rules (4) Most members do not follow the rules (5) Almost all members do not follow the rules (4,5) Less than half of the members follow the rules (-l) MIC (-2) NA
5. RULEFOLLP	Characterize the usual behavior of the appropriators with respect to local operational level rules-in-use related to the resource (e.g., labor and money) provision process in years other than extreme shortage: (1) Almost all members follow the rules (2) Most members follow the rules (1,2) More than half of the members follow the rules (3) About half of the members follow the rules (4) Most members do not follow the rules (5) Almost all members do not follow the rules (4,5) Less than half of the members follow the rules (-l) MIC (-2) NA
6. REALOSER	Are there any appropriators who have been consistently

	disadvantaged in this period? (1) Yes; (0) No; (-1) MIC; (-2) NA
7. WORSTOFF	Have the relatively worst off been cut out of their benefits from this resource or substantially harmed? (1) Yes; (0) No; (-1) MIC; (-2) NA
8. BEGTRUST	As of the beginning of this period, how would you characterize the levels of mutual trust described among appropriators? (1) Moderate to high level of trust (e.g. oral promises given high credence) (2) Modest levels of trust (e.g. oral promises are used but appropriators may be uncertain about performance) (1,2) From moderate to modest levels of trust (3) Low levels of trust (e.g. oral promises rarely used) (-l) MIC (-2) NA
9. ENDTRUST	As of the end of this period, how would you characterize the levels of mutual trust described among appropriators? (1) Moderate to high level of trust (e.g. oral promises given high credence) (2) Modest levels of trust (e.g. oral promises are used but appropriators may be uncertain about performance) (1,2) From moderate to modest levels of trust (3) Low levels of trust (e.g. oral promises rarely used) (-l) MIC (-2) NA
10. TRUSTLEVEL	During this period, has the level of trust among appropriators improved, remained the same, or worsened? (1) Improved; (2) Remained the same; (3) Worsen; (-1) MIC
Overall assessment of successful self-governance of local fisheries	Evaluate whether the fishery system is governed successfully or unsuccessfully (1) Success; (0) Failure Coding tips: 1. Ecological outcomes are assessed as “not declined” unless the resource balance has become worse (Variables 1 and 2) *and* the condition of natural infrastructure has worsened (Variable 3). 2. Social outcomes are assessed as “no conflict issues” only when the rule of law, equity, and trust are *all* assessed as “good”. • Rule of law is assessed as “good” unless more than half of the members violate both resource appropriation (Variable 4) *and* provision rules (Variable 5). • Equity is assessed as “good” unless there are both disadvantaged (Variable 6) *and* worst off (Variable 7) members of the fishing groups. • Trust is assessed as “good” if the level of trust has remained high (Variables 8 and 9) *or* has improved

	among appropriators (Variable 10). 3. Overall outcomes are assessed as "success" if 1) ecological outcomes are assessed as "not declined" *and* 2) social outcomes as "no chronic conflict issues". Otherwise, it is assessed to be not successful.

Table A.3. Coding questions and the seven conditions.

Conditions	Coding Questions
1. ONSTAR	Do group members withdraw ONLY stationary resource units? (1) Yes (0) No (-l) Missing in case
2. LTE100	Are members in a group are equal to or less than 100?: (1) Yes (0) No (-l) Missing in case
3. OZMON	According to Ostrom's design principle 4, "monitors, who actively audit CPR conditions and appropriator behavior, are accountable to the appropriators or are the appropriators" (Ostrom 1990, 94). Are monitors hired by resource users and/or self-organized to form a monitoring team consisting of resource users themselves? (1) Yes (0) No (-l) Missing in case Coding tips The aim of this questions is to capture organized monitoring. For instance, if some rules and techonlogies (e.g., rotational patolling, hiring specialized monitors, and closed-circuit televisions) are used for the sake of monitoring itself, you must code them as (1) Yes.
4. BYMON	According to Ostrom's design principle 4, "monitors, who actively audit CPR conditions and appropriator behavior, are accountable to the appropriators or are the appropriators" (Ostrom 1990, 94). Do resource users monitor each other at low cost because of special environments and/or special appropriation/provision rules? (1) Yes (0) No (-l) Missing in case Coding tips The aim of this quesiton is to capture by-product monitoring that is a spilloever from biophysical and rules-in-use that make it easy for resource users to see opportunistic behaviors. Examples of "special environments" which are conducive to mutual monitoring are small ports, small fishing grounds, etc. An example of "special rules" which is conducive to mutual monitoring is the rule for carrying resource units to the same local marketplace and selling them jointly and simultaneously. Note that biophysical conditions resulting in by-product monitoring do not include resource stationarity.

5. GSANC	Accroding to Ostrom's design principle 5, "appropriators who violate operation rules are likely to be assessed graduated sanctions (depending on the seriousness and context of the offense) by other appropriators, by officials accountable to these appropriators, or both" (Ostrom 1990, 94). Is this design principle present? (1) Yes (0) No (-l) Missing in case Coding tips The aim of this question is to distinguish grauduated sanctions from the following two situations: 1) no gradual increase in sanctions (i.e.,rule violators must be banished); and 2) no actual penalties on rule violations (i.e., only oral warnings are repeated).
6. FCON	Accroding to Ostrom 's design principle 6, "appropriators and their officials have rapid access to low-cost local arenas to resolve conflicts among appropriators or between appropriators and officials" (Ostrom 1990, 100). Are the conflicts resolved through formal processes? (1) Yes (0) No (-l) Missing in case Coding tips The aim of this question is to capture formal mechansims for resolving conflicts. For instance, all members are allowed to hear about rule infractions and make their voice heard in public arena (e.g., monthly group meeting). This is the typical example of "formal process" of conflict resolution.
7. IFCON	Accroding to Ostrom's design principle 6, "appropriators and their officials have rapid access to low-cost local arenas to resolve conflicts among appropriators or between appropriators and officials" (Ostrom 1990, 100). Are the conflicts resolved through informal processes? (1) Yes (0) No (-l) Missing in case Coding tips The aim of this question is to capture informal mechanisms for resolving conflicts. For instance, a few group members who are directly related to the conflict have access to informal arenas (i.e., round table dinner) where influential group leaders play an active role in settling disputes in a more context-specific and sophisticated manner. This is the typical example of "informal process" of conflict resolution.

A good practice for condition selection in intermediate-N (say, 10 to 40 cases) research designs would be to select from 4 to 6-7 conditions (Benoit Rihoux and Ragin 2009). I selected 7 conditions consisting of two contextual and five institutional conditions. Two contextual conditions are resource stationarity (ONSTAR) and group size (LTE100). Five institutional conditions are from Ostrom's Design Principle 4 (monitoring), 5 (graduated sanctions), and 6 (conflict-resolution mechanisms). The presence of the Design Principle

4 is measured in two dimensions, organized monitoring (OZMON) and by-product monitoring (BYMON). The presence of the Design Principle 6 is also measured in two dimensions, formal conflict-resolution mechanisms (FCON) and informal conflict-resolution mechanisms (IFCON). I coded the presence of the Design Principle 5 (GSANC) using Ostrom's definition of graduated sanctions.

Intercoder Reilability
Using the coding questions described in Table A.2 and A.3, two of the authors independently measured 10 outcome variables, assessed overall outcomes ("success" or "not-success"), and coded 7 conditions of each fishing group (30 groups in total). The two coders compared their coding results to identify the mismatched results. They re-analyzed the field reports to reach consensus on the mismatched results. The average of the Cohen's Kappa (Cohen 1960) scores turned out to be 0.594 in my study. According to guidelines provided by Landis and Koch (1977), the Cohen's Kappa values from 0.41 to 0.60 indicate 'moderate' agreement and the values from 0.61 to 0.80 indicate 'substantial' agreement. Hence, the score 0.594 is almost on the borderline between 'moderate' and 'substantial' agreement.

A.3. Procedures and results of comparative analysis

I created a raw data table (Table A.4) in which the overall outcome and the seven conditions are dichotomously valued as "1" (presence of conditions and the occurrence of an outcome) and "0" (absence of conditions and the non-occurrence of an outcome). Each row of the table shows which combination of the seven conditions is *empirically observed* in each fishing group and whether the group is successful or not. Table A.4 shows that there are 23 different combinations of the dichotomously coded conditions.

I then constructed a truth table in which the first seven columns show the presence or absence of the seven conditions and the rows represent all the *logically possible* combinations of the conditions. In a truth table, each row represents a qualitatively different combination of conditions (Schneider and Wagemann 2012). Since my study investigates two different states (presence of absence) of the seven conditions, the truth table must have 128 rows that are identical with the total number of the logically possible combinations of the seven conditions ($2^7 = 128$). Using the fsQCA 3.0 software (Ragin and Davey 2016), I assigned each of the *empirically observed* combinations to the truth table row, then deleted the remaining rows where there are no empirical observations (see Table A.5).

Two major issues should be addressed that may arise when the empirically observed combinations are matched with truth table rows (Ragin 2009; Schneider and Wagemann 2012): logically contradictory cases and logical remainders. In terms of logically contradictory cases, I examined whether an empirically observed combination led to contradictory results of successful and not-successful governance outcome across fishing groups. Such logically contradictory cases were not found in my research. In terms of logical remainders, my study reports that the empirically observed combinations (23 in total) are much less than all the logically possible combinations (128 in total). This means that there are 105 logical remainders (= 128 – 23) which are defined as logically possible, yet empirically unobserved, configurations of the seven conditions.

There are three ways of dealing with the limited diversity of empirical observations (Schneider and Wagemann 2012). First, I can make no assumptions about whether logical remainders produce an outcome (i.e., successful self-governance). Second, I can select only some of the remainders that are useful to simplify solution terms, then assume that those remainders would produce the outcome. Lastly, I can make a knowledge-based expectation of the direction in which each condition influences the outcome. The fsQCA software itself performs the tasks 1) and 2) to generate the maximum complex solution terms and the most parsimonious solution terms, respectively. By inputting the directional expectation of each condition into the software, I completed the task 3) to present intermediate solution terms (Table 3.3) that constitute subsets of the most parsimonious solution terms and supersets of the maximum complex solution terms (Ragin and Davey 2017).

Table A.4. Raw data table.

Group ID	Outcome Success=1; Not-Success=0	Conditions Presence=1; Absence=0						
		ONSTAR	LTE100	OZMON	BYMON	GSANC	FCON	IFCON
1	1	1	1	1	1	1	1	1
2	1	0	1	1	1	1	0	1
3	1	1	1	1	1	0	1	1
4	1	0	1	1	0	1	0	1
5	0	1	0	1	1	1	1	1
6	0	1	0	1	1	1	0	1
7	0	0	1	1	1	0	0	0
8	0	0	1	1	1	0	0	0
9	1	0	0	1	1	1	0	1
10	1	1	1	1	1	1	1	1
11	1	1	0	0	1	0	0	1
12	1	1	0	1	0	0	0	1
13	0	1	1	0	1	0	0	0
14	0	1	1	0	1	0	0	0
15	1	1	1	1	1	0	0	1
16	1	1	1	1	1	0	1	1
17	0	0	1	0	1	0	0	0
18	1	0	1	0	1	1	0	1
19	1	0	1	0	1	1	0	1
20	1	0	1	1	1	1	0	1
21	1	1	1	1	0	1	0	1
22	1	1	1	1	0	1	0	1
23	1	0	1	0	1	0	1	1
24	1	1	1	0	0	0	0	1

25	0	0	1	0	0	0	0	0
26	1	1	0	1	0	0	1	1
27	1	0	1	1	1	1	1	1
28	0	1	1	1	0	1	0	0
29	0	1	0	0	1	1	0	0
30	1	1	0	1	1	0	1	1

The outcome variable is group performance which was dichotomously coded by assigning "1" to successful cases and "0" to not-successful cases. All the seven conditions were also coded as being either present (= "1") or absent (= "0") in each fishing group. See Appendix A.2 for more details on coding questions for 10 outcome variables and 7 conditions.

Table A.5. Truth table for the analysis of sufficiency for group performance.

ONSTAR	LTE100	OZMON	BYMON	GSANC	FCON	IFCON	SUCCESS	# of Cases	Group ID
1	1	1	0	1	0	1	1	2	21, 22
0	1	0	1	1	0	1	1	2	18, 19
0	1	1	1	1	0	1	1	2	2, 20
1	1	1	1	0	1	1	1	2	3, 16
1	1	1	1	1	1	1	1	2	1, 10
1	1	0	0	0	0	1	1	1	24
1	0	1	0	0	0	1	1	1	12
1	0	0	1	0	0	1	1	1	11
1	1	1	1	0	0	1	1	1	15
0	1	1	0	1	0	1	1	1	4
0	0	1	1	1	0	1	1	1	9
1	0	1	0	0	1	1	1	1	26
0	1	0	1	0	1	1	1	1	23
1	0	1	1	0	1	1	1	1	30
0	1	1	1	1	1	1	1	1	27
1	1	0	1	0	0	0	0	2	13, 14
0	1	1	1	0	0	0	0	2	7, 8
0	1	0	0	0	0	0	0	1	25
0	1	0	1	0	0	0	0	1	17
1	1	1	0	1	0	0	0	1	28
1	0	0	1	1	0	0	0	1	29
1	0	1	1	1	0	1	0	1	6
1	0	1	1	1	1	1	0	1	5

This table was generated by the fsQCA 3.0 software (Ragin and Davey 2016). The frequency threshold should be 1 or 2 when the total number of cases is relatively small (Ragin and Davey 2017). The recommended value of the consistency threshold is between 0.8 and 0.9 based on QCA best practices (Basurto 2013). I selected the default values in the fsQCA 3.0: the frequency threshold of 1 was chosen, and the consistency threshold of 0.8 was selected.

Table A.6. Success and not-Success by group

Group performance	# of groups	Group ID
Success	20 (66.6%)	1, 2, 3, 4, 9, 10, 11, 12, 15, 16, 18, 19, 20, 21, 22, 23, 24, 26, 27, 30
Not-Success	10 (33.3%)	5, 6, 7, 8, 13, 14, 17, 25, 28, 29
Total	30 (100%)	

Table A.7. Cross-table comparison between the outcome and the conditions.

		Outcome			
		Success (N=20)		Not Success (N=10)	
Conditions	Presence/Absence	N	%	N	%
ONSTAR	Presence	12	40.00	6	20.00
	Absence	8	26.67	4	13.33
LTE100	Presence	15	50.00	7	23.33
	Absence	5	16.67	3	10.00
OZMON	Presence	15	50.00	5	16.67
	Absence	5	16.67	5	16.67
BYMON	Presence	14	46.67	8	26.67
	Absence	6	20.00	2	6.67
GSANC	Presence	11	36.67	4	13.33
	Absence	9	30.00	6	20.00
FCON	Presence	8	26.67	1	3.33
	Absence	12	40.00	9	30.00
IFCON	Presence	20	66.67	2	6.67
	Absence	0	0.00	8	26.67

The count and percentage of groups, which belong to the corresponding outcome (Success/Not Success) and condition (Presence/Absence), are in the intersection of a row and a column.

Table A.8. The simplified solution formula (not-success).

Not-successful self-governance of local fisheries		
Seven combinations (Intermediate solution†)††	Consistency	Coverage†††
(C1) ONSTAR*lte100*GSANC +	1	0.3
(C2) onstar*LTE100*gsanc*fcon*ifcon +	1	0.4
(C3) lte100*ozmon*fconi*fcon +	1	0.1
(C4) LTE100*bymon*fcon*ifcon +	1	0.2
(C5) ozmon*gsanc*fcon*ifcon	1	0.4

- Acronyms: ONSTAR (only stationary resources); LTE100 (≤100 members); OZMON (organized monitoring); BYMON (by-product monitoring); GSANC (graduated sanctions); FCON (formal conflict resolution); IFCON (informal conflict resolution)
- Lowercase characters represent the absence of the condition.
- Boldface letters are used to emphasize two contextual conditions (resource stationarity and groups size).
- The symbol of "+" represents the logical operator OR and the "*" represents AND.

Solution coverage = 1; Solution consistency = 1

† As recommended by Ragin (2008), I based my combinations on the intermediate solution that requires us to use theoretical and substantive knowledge about influence of each condition on the outcome. Based on discussion about the seven conditions in Section 2 and 3, I expected that LTE100 could contribute to not-success when it is present or absent, and that the rest of the conditions could contribute to the outcome when they are absent. Using these directional expectations, the fsQCA software 3.0 (Ragin and Davey 2016) computed the intermediate solution.

†† C1 explains the not-success of self-governing organizations, including Group ID 5, 6, and 29; C2 does 7, 8, 17, and 25; C3 does 29; C4 does 25 and 28; C5 does13, 14, 17, and 25. Group ID is a case number assigned to each of 30 self-governing organizations (see Appendix A for more details on Group ID and locations on map).Note that the not-success of a group (e.g., Group 29) can be explained by multiple paths (e.g., C1 or C3) because of equifinal causation which means that different combinations of conditions might lead to the same outcome (see Subsection 3.2).

††† I used raw coverage defined as the number of cases following a specific path to the outcome divided by the total number of instances of the outcome (Ragin 2008)

APPENDIX B

ODD PROTOCOL FOR CHAPTER 4

Model Description: ODD Protocol

This is a model description of an original model discussed in Chapter 4. The model description follows the ODD protocol for describing individual- and agent-based models (Grimm et al. 2006) and consists of seven elements. The first three elements provide an overview, the fourth element explains general concepts underlying the model's design, and the remaining three elements provide details. Additionally, details of the software implementation are presented.

1. Purpose

The purpose of this model is to investigate under what set of socioeconomic conditions the exit option – *neither producing a local public good nor consuming the public good produced by others* – works effectively to enhance levels of cooperation in the long run. The exit option conceptually differs from defection which is defined in public goods games as consuming a public good produced by others without contributing to the provision of the public good. A major economic condition of interest in this model is different levels of the exit payoff that affects individual decisions to participate in collective action for public goods provision. A social condition is an intergroup interaction through which more successful groups take over other groups (cultural group selection).

2. State variables and scales

An artificial society of this model consists of 128 groups. Each group has a size n which is varied in the simulations. Each group provides a local public good in two different situations. In the absence of exit (namely, without-exit situation), members of each group can choose three strategies: defection, cooperation without punishment, and cooperation with punishment. These strategies interact and propagate through both individual imitation of high payoff behaviors and cultural group selection. In the presence of exit (namely, with-exit situation), the exit option is available to members of each group besides the three strategies above. Note that like the without-exit situation, these strategies interact and propagate through the two mechanisms, such as individual payoff-biased imitation and cultural group selection.

3. Process overview and scheduling

<u>1) Without-exit situation</u>

Like Boyd et al. (2003), initially one group consists of all punishing cooperators and the other 127 groups consist of all defectors. Each time period (tick) comprises five sequential stages. First, each member in a group first decides whether to cooperate or defect. Second, each cooperator decides whether to punish a defector. Third, each member in a group encounters a randomly chosen member from the same group or from other groups to imitate high payoff behaviors (individual payoff-biased imitation). Fourth, each group is randomly paired with one of the other groups so that a more successful group takes over another group (cultural group selection). Finally, a small change of mutation occurs to each member (e.g., cooperator flips to a defector).

2) With-exit situation

The initial setting of this model is the same as in the without-exit situation: one group consisting of all punishing cooperators and the remaining 127 groups consisting of only defectors. During each time period (tick), the five steps described in the without-exit situation also are taken: contribution with erroneous defection, punishment on defection, individual imitation, group interaction, and mutation (e.g., defectors flip to exiters). Note that an initial introduction of the exit option to group members is attributed to mutation.

4. Design concepts

- *Emergence*. Emergence of cooperators (including punishing cooperators) who produce a local public good.
- *Adaptation*. Groups adapt their composition of members through multilevel selection mechanisms, such as individual payoff-biased imitation, mutation, and intergroup interaction.
- *Fitness*. The fitness of a group for cultural group selection is associated with the frequency of cooperators (including punishing cooperators) or the frequency of exiters.
- *Interaction*. Individuals interact through payoff biased imitation, and groups interact via cultural group selection.
- *Stochasticity*. (1) Probability of mutation: individuals of each type spontaneously switch into one of the other types; (2) Probability of mixing between groups: individuals encounter an individual from another randomly chosen group; and (3) Probability of cultural group selection: groups are randomly paired to take over other groups.

5. Initialization

Simulations start with one group consisting of only punishing cooperators and the other 127 groups consisting of only defectors.

6. Input

Boyd et al. (2003) do not consider the exit option but incorporate individual payoff-biased imitation and cultural group selection. The current study aims to compare the results of the without-exit situation to those of the with-exit situation in order to investigate the effects of exit on cooperation. To make a *ceteris paribus* setting for the cross-model analysis, the default values of most of parameters in this model are set to be the same as in Boyd et al. (2003).

Default parameter values

- $N = 128$; Number of groups (Boyd et al. 2003)
- $n = 20, 40, 60, 80, 100, 120$; Number of members in a group
- $b = 0.5$; Benefit if everyone cooperates (Boyd et al. 2003)
- $c = 0.2$; Cost of cooperation (Boyd et al. 2003)
- $p = 0.8$; Cost of being punished (Boyd et al. 2003)
- $k = 0.2$; Cost of punishing (Boyd et al. 2003)
- $m = 0.01$; Rate of mixing between groups (for individual imitation) (Boyd et al. 2003)
- $\mu = 0.01$; Mutation rate (Boyd et al. 2003)
- $s = 0.015$; Rate of group pairing (for cultural group selection) (Boyd et al. 2003)
- $e = 0.02$; Erroneous defection rate (Boyd et al. 2003)
- $\Omega = 0.800, 0.925, and\ 1.05$; Exit payoff

7. Submodels

Here, I describe submodels, one of which has no exit option (without-exit situation) and the other has the exit option (with-exit situation). Each group produces a local public good in the two different model, respectively.

1. Without-exit situation (Following Boyd et al. (2003))

- The payoff for a nonpunishing cooperator is $\boxed{1 + bx - c}$, where x is the fraction of nonpunishing and punishing cooperators in a group.
- The payoff for a defector is $\boxed{1 + bx - py}$, where y is the fraction of punishing cooperators in a group.
- The payoff for a punishing cooperator is $\boxed{1 + bx - c - k(1 - x)}$

Individual Imitation

Members in a group encounter another member from their own group with probability $1 - m$ and a member from another randomly chosen group with probability m $(= 0.01)$. A member i who encounters a member j imitates j with probability $\frac{w_j}{(w_j + w_i)}$, where w_q is the payoff of member q in the game, including the costs of punishing and being punished. This individual imitation leads to not only the spread of higher payoff behaviors within group, but also diffusion of the behaviors between groups with probability m.

Cultural Group Selection

In each time step, group selection occurs through the *More-Coop* group interaction. The process of the *More-Coop* group interaction is as follows. Each group is randomly paired with one of the other groups with probability s $(= 0.015)$. Their interaction results in one group taking over another group. The probability that group i

takes over group j is $0.5\{1 + (x_i - x_j)\}$, where x_g is the frequency of nonpunishing and punishing cooperators in group g. This means that the group with more cooperators is more likely to take over another group with fewer cooperators. As a result, cooperation is the sole target of the resulting cultural group selection process.

2. With-exit situation

- The payoff for a nonpunishing cooperator is $\boxed{1 + bx - c}$, where x is the frequency of nonpunishing and punishing cooperators.
- The payoff for a defector is $\boxed{1 + bx - py}$, where y is the frequency of punishing cooperators.
- The payoff for a punishing cooperator is $\boxed{1 + bx - c - k(1 - x - z)}$, where z is the frequency of exiters.
- In line with Hauert et al. (2007), the exit payoff (Ω) is exogenously given to group members while the payoffs for participants in collective action vary with endogenous population dynamics. Because the amount of exit payoff is critical to individual decisions to participate in collective action, this model gives exiters different payoffs ($\Omega = 0.800, 0.925, and\ 1.050$) to examine effects of the exit payoff on the frequency of cooperation. Once one of the exit payoffs is given to a simulation, it is constant throughout the simulation. Such exit payoffs are set to be the same as the payoff that nonpunishing cooperators obtain (1) when no members within a group contribute to local public goods, (2) when 25% do, and (3) when 50% do. Hence, three levels of the exit payoff are $\boxed{1 + b \cdot 0 - c}$, $\boxed{1 + b \cdot 0.25 - c}$, $\boxed{1 + b \cdot 0.5 - c}$, respectively.

Individual Imitation

Same as in the without-exit situation

Cultural Group Selection

In the with-exit situation, I investigate how two different types of intergroup interaction affect levels of cooperation in the long run. First, like the without-exit situation, the *More-Coop* group interaction also occurs in the with-exit situation. Besides the *More-Coop*, the *Less-Exit* group interaction occurs that results in a group with fewer exiters taking over another group with more exiters. The *Less-Exit* starts with having groups paired at random and with probability s. Then, cultural group selection between the paired groups occurs to reduce the number of exiters. The probability that group i takes over group j is $0.5\{1 + (z_j - z_i)\}$, where z_g is the frequency of exiters in group g. This means that the group with fewer exiters is more likely to take over another group with more exiters.

8. Model implementation

Model is implemented in Net Logo 6.1.1. I followed Boyd et al. (2003) both in terms of a span of simulation time (time step = 1 year) and a way of calculating the long run average frequency of cooperation (including nonpunishing and punishing cooperators). Each result is the average of 100 simulations. Following Boyd et al. (2003), the current study reports for each simulation the average frequency of cooperation over the last 1,000 time periods of a 2000 time period simulation. These results are plotted in Fig. 4.1 (the *More-Coop* group interaction) and 4.2 (the *Less-Exit* group interaction).