Using the IGT and QCA to evaluate the institutional structures of water quality trading programs

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Abstract

Payments for ecosystem services have emerged over the past two decades as a new approach to modifying behavior by natural resource users and for securing beneficial ecosystem processes that originate from private lands. The accepted definition of payments for ecosystem services—a voluntary, conditional transaction of a well-defined ecosystem service between at least one buyer and one seller—is seemingly simple. However, this definition implicates a complex set of rules, from how an ecosystem service is defined, to who can participate in a transaction as a buyer or a seller. Decisions about how to structure a PES program can have a significant impact on the eventual success or failure of the program to achieve its ecological, economic, and equity goals. Here, I apply the rules-based classification system developed by Lien et al. to systematically model the impacts of PES program design decisions on outcomes. The classification system is grounded in the Institutional Grammar Tool (IGT). The IGT enables detailed evaluation of the individual components of rules, laws, and regulations. Qualitative comparative analysis (QCA), a method for assessing differences in qualitative datasets, is used to identify similarities and differences in how rules structure interactions between actors involved in PES programs that seek to improve water quality in the United States. The results of this work highlight key program design elements held in common by effective programs, as well as design features that respond to the unique needs of individual communities. By identifying essential program design features and rules, the outcomes of this work provide valuable new information about what governance arrangements are commonly associated with effective implementation of PES programs and the critical gaps often present in stalled or ineffective programs.

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1. Introduction

From the initial implementation of Costa Rica's forest conservation payments program in the 1990s, payments for ecosystem services (PES) have become a common approach to implementing conservation programs around the world (Wunder et al., 2018). The types of activities supported by these programs and the resources they seek to conserve has similarly expanded to cover a wide range of conservation, economic development, and equity goals (Derissen and Latacz-Lohmann, 2013). Despite the staying power and popularity of PES approaches in the conservation community, however, there are still significant knowledge gaps about what makes PES programs more or less effective in achieving their stated goals, especially from an institutional perspective. Much of the existing research has taken either a case study or theoretical approach, providing data about what worked or did not work in specific circumstances (Bronner et al., 2013; Coggan et al., 2013; Balvanera et al., 2012; Corbera et al., 2009) or establishing how to apply frameworks and select variables for generalizable study of PES (Bennett and Gosnell, 2015; Huber-Stearns et al., 2015; Matzdorf et al., 2013; Muradian and Rival, 2012). Building on this previous work, there is a need for moderate- to large-n studies to develop generalizable knowledge about the relationship between institutional design of PES programs and program effectiveness. Here, I analyze 20 water quality trading PES programs using qualitative comparative analysis (QCA) to determine if there are consistent patterns in institutional arrangements across effective programs that point to the importance of particular design features or principles.

While PES programs vary considerably in purpose and approach, they all share several basic characteristics that are inherent to the definition of PES. The most widely accepted definition of PES is the exchange of something of value, generally money but also other goods of value such as conservation planning assistance or materials, between at least one seller and one buyer, in exchange for the continuous provision of a specified ecosystem service for the entire duration of a specified contract period (Wunder et al., 2018; Wunder, 2005). This final requirement is termed "conditionality" because payment is conditional on the continuous provision of the ecosystem service. In addition, PES generally requires "additionality," or some assurance that the activity undertaken by the seller is the result of the payment the seller is receiving from the buyer and not something the seller otherwise would have done regardless of payment (Banerjee and Secchi, 2013). PES programs are used to address a wide range of resource management concerns, including water pollution (Bennett et al., 2014; Bennett and Carroll, 2014), deforestation (Legrand et al., 2013; Mislimshoeva et al., 2013; Prokofieva and Gorriz, 2013; Corbera et al., 2009), carbon sequestration (West et al., 2018; Dwivedi et al., 2012; Corbera et al., 2009), and wildlife habitat conservation (Hansen et al., 2018; Wilson et al., 2017), and to encourage implementation of management practices, such as agricultural management practices to prevent erosion and protect wildlife habitat (Chamberlain and Miller, 2012; Claassen et al., 2008; Feather et al., 1999).

In many cases, PES is used as a means to encourage individual private land owners to address the negative externalities associated with natural resource use and extraction on public goods and common pool resources. For example, water quality in lakes and streams is a common pool resource—it is difficult to restrict pollution from diffuse, non-point sources such as agriculture and individual lakes and streams have a limited ability to absorb additional pollution without adverse effects on water quality, aquatic organisms, and human use for drinking water and recreation. Similarly, the atmosphere is a global common that is used by all countries as a sink for industrial pollution known to diminish air quality locally and contribute to human caused climate change globally. PES programs seek to mitigate these externalities by paying, for example, farmers to implement management that decreases non-point source pollution to lakes and streams. As such, PES programs are often designed to provide resource users with an economic incentive to modify behavior in a way that reduces use of the commons or offsets for the use of the commons by others.

As the number of PES programs has proliferated globally, interest in measuring their effectiveness for addressing targeted environmental problems has increased (Lima et al., 2019; Ferraro and Pattanayak, 2006). This research has generally used one of two approaches: case study analysis and theory development and application of theory. Case study approaches seek to increase understanding of PES effectiveness through in-depth study of one or a few specific PES programs. These studies are useful for understanding the specific circumstances of why different programs are more or less successful and, over time, should contribute to generalized knowledge about the implementation and effectiveness of PES through metanalysis and similar approaches. Theoretically motivated studies of PES have focused largely on institutional and governance dimensions of how programs are structured and function. By encouraging researchers to consider a common theoretical frame of PES research, these studies are especially useful as guides for improving the comparability of future research. Recently, more studies have begun to take a theoretically rigorous approach to studying PES programs by applying tools from institutional analysis and common pool resource theory. This paper builds on this research and fills a gap by explicitly focusing on the effectiveness of PES programs using institutional analysis methods.

The Institutional Analysis and Development (IAD) framework provides a general structure for understanding the relationships between actors and how actors interact to produce outcomes in a given institutional setting (Figure 1). Institutions are the common set of rules, strategies, and norms that structure and guide repeated human interactions (Ostrom, 2005). The IAD framework is well suited for the study of PES approaches. Each PES program is a collection of institutional arrangements—rules, norms, and strategies—that make up the overall institution of, say, a water quality trading scheme for the Ohio River. Nested within the IAD framework is a more detailed structure for understanding institutional arrangements as collections of specific types of rules that require, permit, or restrict behaviors (Figure 2). These rule types directly affect the various elements that make up a given action situation. Through application of the Institutional Grammar Tool (IGT), a method of classifying rules by their function in action situations, it is possible to model action situations (Crawford and Ostrom, 1995). This model can in turn be used for diagnostic analysis to identify gaps in institutional arrangements and, in combination with theory, suggest how different combinations of institutional arrangements affect outcomes.

Figure 1: The IAD framework. The action arena is the focal unit of analysis. Action arenas are affected by exogenous variables, interactions between actors, and outcomes of action situations. The outcomes of any single action situation may be linked to other action situations, forming networks of action situations. Reproduced from Ostrom, 2005.

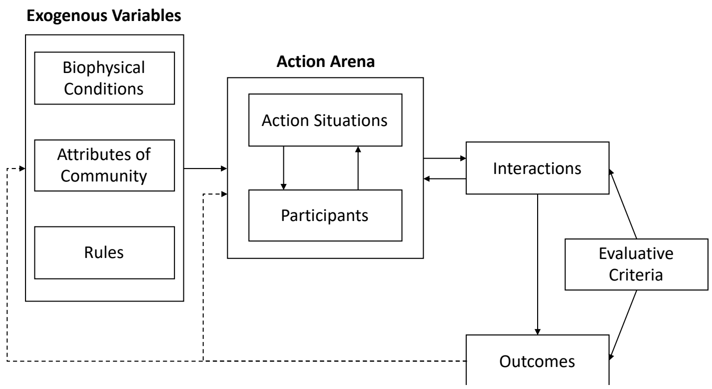
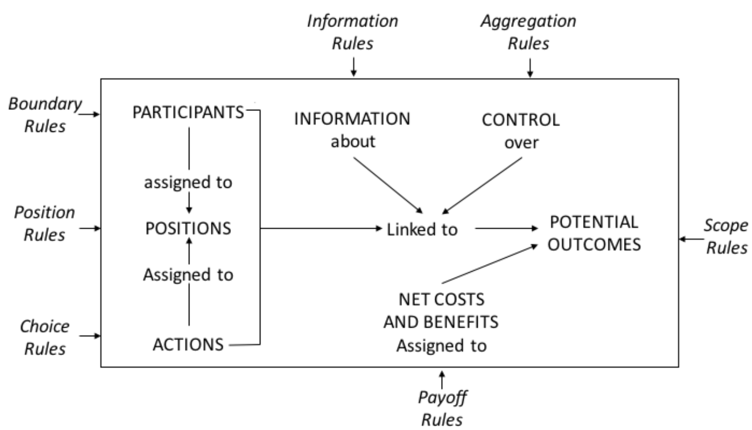


Figure 2: Diagram showing how different rule types relate to different aspects of an action situation. Reproduced from Ostrom, 2005.



I use the IAD framework to structure a comparative study of water quality trading PES programs to begin to identify how program design effects program effectiveness. This work is guided by PES theory and practice. PES theory is used to identify the function of different rule types and action situations in institutions—the critical points of interaction between actors in the process of developing and executing water quality trading transactions. I use QCA, a structured approach to qualitative data analysis of binary data using Boolean algebra (Rihoux and De Meur, 2009), to test for the importance of certain rule configurations for program effectiveness. The results of this work contribute to knowledge about the design and effectiveness of PES approaches by adding to the limited number of moderate- to large-n PES studies and demonstrating the utility of diagnostic institutional analysis methods for the study of PES programs.

2. Methods

I apply previous work to develop a rules classification scheme for water quality trading programs (Lien et al., 2018) to identify the institutional arrangements that structure each of these programs based on rules-in-form—the written rules of each PES program assessed. I then apply QCA to assess the importance of the presence or absence of different rule types across programs and to identify commonalities and differences between effective and ineffective programs. This research is exploratory in nature. QCA has not been previously applied to analysis of PES program institutional form. Therefore, a primary goal of this research is to determine if valid and useful results can be generated using this approach. For the purposes of this work "effective" is defined simply as programs where there is publicly available information indicating that a transaction had taken place prior to 2018. The following sections describe each step in this analysis in more detail.

2.1 Case selection and rules coding

I coded institutional arrangements for 20 water quality trading state and local programs. Nineteen of these programs were located in the United States and one was located in Australia. Programs were identified using a review of literature on water quality trading (Willamette Partnership, 2015; Bennett et al., 2014; Bennett and Carroll, 2014; Greenhalgh and Selman, 2012). This literature review resulted in an initial set of 80 water quality trading programs. This set of 80 programs was refined on the basis of two criteria: 1) the program has a primary focus on water quality trading and 2) information detailing the institutional arrangements of a program, e.g. program bylaws or state or local laws, was publicly available. These filters resulted in our final set of 20 programs for evaluation; though only one program was located outside the United States (US), its approach to water quality trading was similar to the US examples, so it was retained in the sample.

After acquiring program documentation for each of the 20 water quality trading programs, the IGT was applied to code individual rule statements according to the type and purpose of each rule (Ostrom, 2005; Crawford and Ostrom, 1995). Rule coding followed the methods established by Basurto et al., 2010 and Feiock et al., 2016. The goal of rule coding was to develop a system for classification of general functions of rules within PES program institutions. Rules were first coded by type: position, boundary, choice, aggregation, information, payoff, or scope. Each rule type permits, restricts, or requires a different type of action. For example, payoff rules are used to specify the distribution of costs and benefits within an institution. In the case of PES programs, payoff rules relate to how much credits cost, the lifetime of credits, timing of transactions, etc. Then, the function of the rule within the water quality trading program was specified. For example, a boundary rule may have the function of establishing eligibility for participating in a program as a buyer based on the possession of certain credential. This process was carried out for all 20 water quality trading programs evaluated. The result of the coding process is a complete rules classification scheme for water quality trading programs that specifies generic rule functions for each rule type. More specific information about the coding process and the construction of the classification system is available in Lien et al., 2018. The classification system is the basis for the QCA.

2.2 Defining effectiveness

Effectiveness of PES programs generally and water quality trading schemes specifically is difficult to assess. There is no agreed upon standard for success of PES programs in the literature because the goals of programs vary widely. Some PES programs are focused solely on ecological outcomes, but many also have co-equal or secondary economic development and equity goals. Ideally, it would be possible to evaluate the effectiveness of PES programs in terms of ecologic, equity, and economic outcomes. In practice, however, any given method is limited in its ability to jointly assess this full range of outcomes, especially when moving beyond case study and small-n research to moderate- to large-n research.

Here, I adopt a simple measure of effectiveness—was there publicly available evidence that a water quality trading transaction had taken place under the auspices of a given water quality trading scheme at the time of analysis (2018). This is a seemingly low bar; water quality trading programs are ostensibly designed to allow for enough transactions to achieve measurable decrease the level of water pollution in a receiving water body. In practice, however, many water quality trading schemes have struggled to develop transactions. Within my dataset, six programs have no available evidence of transactions. For an additional five programs, there is some information available that indicates a transaction may have taken place, but no clear record of a transaction. These eleven programs are coded as ineffective. The remaining nine programs have all had one or more transactions take place and are coded as effective.

Poorly designed institutions are not the only explanation for program ineffectiveness. However, other problems in program development and design, such as lack of stakeholder engagement in the development process or inadequate supply and demand for ecosystem service flows, may be a reflection of institutional design. The design principles for well-functioning common pool resource systems (Ostrom, 1990) provide a set of expectations for institutional design that can be tested by comparative analysis of programs to identify of candidate design principles that may be particularly important to the design of PES programs. These candidate design principles may extend beyond those originally articulated by Ostrom, 1990 and tested by Cox et al., 2010 to include principles unique to the specific case of PES programs.

2.3 Modeling PES Institutions

To test the effectiveness of the 20 water quality trading schemes identified for this study, I conducted a QCA using the generic rule types identified using the rules classification system described in section 2.1. This comparative analysis took place at two levels to identify patterns of differences between programs. First, I developed a binary classification of presence or absence of different rule types for each program using the second and third tier variables from the rules-based classification system for PES programs (Lien et al., 2018). Second, I conducted a more specific QCA analysis on specific action situations.

The first analysis required minimizing sometimes large sets of rules to a simple, binary determination of presence or absence. The rules for this determination are provided in Table 1. These rules are based on PES theory and practice. The definition of PES provides specific expectations for the presence of a fundamental set of linked action situations that taken together make up the basic structure of any PES program. These action situations include, at minimum: establishment of eligibility for buyers and sellers, the process of creation of an ecosystem service for exchange, the actual exchange of the ecosystem service, and monitoring to ensure conditionality. The expectation that programs will include this set of action situations also sets clear expectations for the types of rules that should be present within each PES institution as a whole. Eligibility action situations likely require boundary rules that set qualifications for the position of buyer or seller, choice rules about what actions must be taken to gain these qualifications, and information rules about establishing qualifications. Creation of an ecosystem service likely requires particular actions on the part of sellers (choice rules), application requirements (information rules), and may set expectations for costs and benefits (payoff rules).

Table 1: Coding guidelines for dichotomizing presence/absence of program institutional arrangements

Rule Type	Rule Present	Rule Absent
Position	At least three position categories OR both buyer and seller rules present	Rules in only 1 or 2 categories AND absence of both buyer and seller rules (if both buyer and seller rules are present, but not other positions, rate a 1)
Boundary	Credential and/or procedural boundary rules are present for both buyers and sellers. Rules may be compound buyer/seller rules to meet this criterion	Credential and/or procedural boundary rules are absent for both buyers and sellers
Aggregation	Rules present from 3 or more categories of aggregation rules	Rules present form 2 or fewer categories of aggregation rules
Payoff	At least one payoff rule in each of the following categories: buyer payoff, seller payoff, intermediary payoff, misc. payoff rules.	At least one payoff rule in each of the following categories: buyer payoff, seller payoff, intermediary payoff, misc. payoff rules.

Information	Rules present in more than half of the information rule categories	rules present in less than half of the information rule categories
Choice	At least one choice rule in each of the following categories: buyer/seller, regulator, intermediary	At least one choice rule in each of the following categories: buyer/seller, regulator, intermediary
Scope	Two or more scope rules	One or fewer scope rules

In reality, each of the five basic action situations implicated by the definition of PES programs is likely made up of a complex network of smaller action situations that are linked by outcomes. The goal of this analysis, however, was to attempt a much-simplified analysis to determine the utility of the rules classification system and QCA for parsimonious large-n institutional analysis of PES programs. Therefore, as a first step, I did not look within individual action situations, but rather tested general categories of rules across action situations. In this analysis, the set of present or absent rules are the independent variable and program effectiveness is the dependent variable.

H1: Effective water quality trading programs share certain combinations of rule types and functions; ineffective programs lack these combinations of rule types and functions.

Second, I took a limited look inside individual action situations to analyze the importance of differences in the structure of common action situations on effectiveness across programs, using QCA results from the initial analysis to guide analysis of differences. This analysis again relied on the rules classification system for PES programs but assigned third-tier rule types to structure specific action situations. In this analysis, the rules structuring each action situation are the independent variables and program effectiveness is the dependent variable. I tested two action situations using this approach: buyer eligibility and seller eligibility. Both of these action situations are essential components of any PES institution. To succeed, a program must have ecosystem service sellers willing to develop credits and buyers willing to purchase these credits.

> *H2: Effective water quality trading programs will have action situations with sets of rules that are consistent with the findings of the QCA analysis.*

2.4 Qualitative Comparative Analysis

Use of generic rules to model action situations is necessary to enable comparative analysis. Rules are written to apply to the specific circumstances and idiosyncrasies of a given community and biophysical setting (Ostrom, 2005). Because of this, if specific rules were used for comparative analysis, there would likely be little to no overlap between programs. However, by using generic rules that specify the function and purpose of the underlying specific rule, I am able to generalize rule statements to a level that allows for comparative analysis without losing sight of the function of a given rule in the structure of an individual action situation.

Qualitative comparative analysis is a structured, rigorous approach to comparative analysis of multiple cases. At a basic level, QCA is a method for identifying differences and commonalities across cases and logically connecting this differences and commonalities to outcomes. It is generally used to identify causal linkages between variables in small to moderate-n research and is best suited to studies where the researcher has intimate, detailed knowledge of the cases under analysis (Berg-Schlosser et al., 2009). As a result, QCA may be particularly well suited to institutional analysis. In this study, I have extensive knowledge of each case as a result of coding individual rule statements for each water quality trading program. I understand how rules relate to one another within a program from this analysis and can also relate these rule structures to expectations about the structure of PES programs from literature and practice.

Implementation of QCA involves selection of a set of theoretically informed independent variables, a dependent variable, coding of individual cases for the presence or absence of independent variables, and formal comparison using Boolean algebra to determine the combinations of independent variables present or absent in different outcomes of the dependent variable. (Berg-Schlasser et al., 2009). The overall goal of QCA is to identify a parsimonious explanation of the causal relationship between different combinations of independent variables that lead to a positive result for the dependent variable.

Implementation of QCA in this study followed the following steps: 1) variable selection; 2) dichotomization of independent and dependent variables; 3) selection of independent variables to include in the analysis; 4) carry out QCA analysis by constructing truth tables, identifying and correcting if possible contradictory configurations of independent variables, visualizing results, and identifying minimum configurations of independent variables that result in a positive outcome for the dependent variable (Rihoux and De Meur, 2009). All analysis was conducted using the QCA package in R: a language and environment for statistical computing (Dusa, 2019; R Development Core Team, 2018). The dependent variable for both H1 and H2 was the same: program effectiveness as determined by publicly available evidence of a water quality trade having taken place, coded 1 if yes, and 0 if no. Similarly, for both H1 and H2, independent variables were all rule types in the IAD rules typology. To assess H1, I implemented the coding scheme shown in Table 1 to dichotomize basic rule types, e.g. position, boundary, choice, etc., by binary presence or absence. To assess H2, I assessed presence or absence of each rule type in the two action situations observed and used the detailed data available on the function of each rule type in the action situation to add a second level of qualitative interpretation of the results.

3. Results

I present results organized by hypothesis. For H1, I summarize the results of QCA of general rule types and functions across water quality trading programs. For H2, I zoom in to specific action situations to assess the effect of combinations of rules within actions situations. These data are heavily summarized to enable a reasonable presentation of the results. I elaborate on the implications of these findings in the discussion section.

3.1 QCA analysis of rule configurations across programs

Table 2 shows the results of coding presence/absence of rule types for each program analyzed and the outcome of each program. Even before performing QCA, several patterns are evident in the data. First, nearly all programs specify boundary rules. This is consistent with expectations from PES theory. Boundary rules set the qualifications for participating in a given institution. Without boundary rules, actors do not know if or under what conditions they are permitted to participate in an institution. Therefore, it is expected that every program will have clear rules about the conditions under which an actor may or may not participate in trading. Only one program does not have boundary rules that meet the minimum standards of the coding scheme. In contrast, aggregation rules—rules about decisionmaking processes within an institution—are rare. Only one program was coded as having aggregation rules present. Finally, scope rules were also very common. All but one program was coded having present scope rules. Scope rules address outcomes of institutions and are expected under PES theory because PES institutions are specifically outcomes-based. PES institutions may not specify the manner by which ecosystem services are provided, only the desired outcome of increased ecosystem services (or decreased ecosystem disservices) of some type.

Table 2: Results of dichotomizing presence/absence of program institutional arrangements

		Rule Type						
Name	Outcome	Position	Boundary	Aggreg.	Payoff	Info.	Choice	Scope
A	1	0	0	0	1	0	1	1
B	0	0	1	1	0	1	0	1
C	0	0	1	0	0	1	1	1
D	0	1	0	0	1	1	0	1
E	0	1	1	0	0	0	1	1
F	1	0	1	1	1	0	0	1
G	1	0	1	0	0	1	0	1
H	0	0	1	0	0	0	0	1
I	1	1	1	0	1	0	1	1
J	1	1	1	0	1	1	0	1
K	0	1	1	0	0	1	1	1
L	0	0	1	0	0	0	0	1
M	0	0	1	0	0	0	1	1
N	0	0	1	0	0	0	1	1
O	1	0	1	0	0	0	0	1
P	1	1	1	0	0	1	0	1
Q	1	0	1	0	0	0	0	1
R	1	1	1	0	1	1	1	0
S	0	0	1	0	0	0	0	1
T	0	0	1	0	0	1	1	1

Because boundary and scope rules are nearly universally present and aggregation rules are nearly universally absent, these rule types of little importance in the execution of the QCA analysis. The QCA process is looking for differences between programs in the presence and absence of causal variables. If there is no variance across programs, the inclusion of a variable will only serve to increase the complexity of the analysis by increasing the number of possible combinations of variables. Therefore, the QCA included position, payoff, information, and choice rules as independent variables explaining the effectiveness or ineffectiveness of water quality trading programs. This resulted in 16 possible combinations of variables.

The results of the construction of the truth table is shown in Table 3. The truth table shows how different combinations of rule types are associated with different program outcomes. There are five effective programs with different combinations of rules, three combinations of rules aligned with both effective and ineffective programs, and four combinations of rules associated only with ineffective programs. In general, QCA seeks to avoid combinations of independent variables that result in contradictory results on the outcome variable. To eliminate contradictions, the analyst my apply changes in the coding regime that are supported by theory or case specific knowledge to account for differences that were not initially captured in binary coding (Rihoux and De Meur, 2009). I took the latter approach. To address contradictions the following changes were made based on case-specific knowledge:

- Program J was recoded to have choice rules present rather than absent
- Program G was recoded to have payoff rules present rather than absent
- Program O was removed from the dataset
- Program Q was recoded to have position rules present rather than absent

Table 3: Truth table for final QCA of water quality trading programs

Rule Types					
Position	**Payoff**	**Info.**	**Choice**	**Outcome**	**Cases**
0	1	0	0	1	F
0	1	1	0	1	G
1	0	0	0	1	Q
1	0	1	0	1	P
1	1	0	1	1	I
1	1	1	1	1	J, R
0	0	0	0	0	H, L, S
0	0	0	1	0	M, N
0	0	1	0	0	B
0	0	1	1	0	C, T
1	0	0	1	0	E

1	0	1	1	0	K
1	1	1	0	0	D
0	1	0	1	-	-
0	1	1	1	-	-
1	1	0	0	-	-

Program J has robust choice rules in place. However, because no intermediary rules were present, it did not meet the initial coding criteria. Based on case knowledge, it was determined this coding was errant. The program has rules that apply to regulators that effectively allow them to fill the rule of intermediaries in other programs. Similarly, the Program G has robust payoff rules in place but lacks clear rules for intermediary payoffs. This program, however, does not have intermediary rules in any rule category indicating that the program may not have been designed with intermediaries in mind. Program O was removed because it is largely a collective choice rather than operational institution. The other programs analyzed here are largely operational level institutions; including program O may result in inconsistencies. Finally, program Q did not have clear buyer and seller positions but did specify regulated parties. Because Program Q applies to regulated water treatment facilities, rules for regulated parties are equivalent to rules for buyers and sellers.

These changes eliminated all contradictory configurations. The updated truth table includes seven rules configurations consistent with positive outcomes and seven rule configurations consistent with negative outcomes. Table 4 shows the results of Boolean minimization of the truth table to identify the combinations of variables explaining effectiveness. After minimization, program A was identified as a unique outlier in that the absence of information rules is important for effectiveness. For all other effective programs, effectiveness was a function of position, payoff, and choice rules. Specifically, the presence of position, payoff and choice rules; or the presence of position rules and the absence of payoff and choice rules; or the presence of payoff rules and the absence of position and choice rules explain effectiveness. The fact that program A is an outlier is consistent with context; it was developed prior to most of the other programs considered and is unique in its structure and the communities targeted as sellers, primarily Amish farmers.

Table 4: Boolean minimization of relationship between rule types and program effectiveness; CAPS indicates presence of rule type, lower case indicates absence

Boolean Expression	**Cases**
POSITION*PAYOFF*CHOICE	I, J, R
POSITION*payoff*choice	Q, P
position*PAYOFF*choice	F, G

3.2 Comparative analysis of rules within action situations

While a large amount of variance in the specific rules used by different programs is expected owing to different biophysical and community attributes, generalization of these rules into broader categories defined by rule function was expected to increase the number of rule types held in common across programs. While this did occur to a certain degree, there was still significant variation across programs in the types of rules used in different action situations and the number of rules present in different action situations. Looking within action situations helps to contextualize the importance of the rule types identified as important to effectiveness by QCA in the previous step.

Eligibility rules for buyers and sellers are a basic building block of water quality trading programs and PES institutions generally. The outcome of each eligibility action situation is either an actor is eligible to sell (or buy) water quality credits in the water quality trading market or an they are not eligible to sell (or buy) water quality credits. Without these outcomes, buyers do not know who to approach for credits to offset pollution and sellers do not know who to market credits to or the potential depth of the buyer market, a factor important for understanding buyer demand.

General rules of all types except for scope and aggregation rules were observed in these action situations, with little pattern between effective and ineffective programs. Only two effective programs specifically define the position of seller, while four ineffective programs do the same. In contrast, of the four programs with a buyer position specified, three were effective and only one was ineffective. Both effective and ineffective programs frequently define a general position of regulated parties that the trading regulations apply to that may be occupied by either buyers or sellers (6 vs. 5, respectively).

Choice, information, and payoff rules were highly diverse in all action situations—across all programs, there were more of these types of rules than any other rule type. Choice rules define the specific actions one must take to gain eligibility. For example, if an actor must take certain actions to gain a credential. Nearly all programs (17 of 20) have specific choice rules about actions required in the process of applying for eligibility. Information rules may specify what, how, and when information must be shared in order to gain eligibility. Again, most programs (15 of 20), effective and not had specific rules related to the information that must be contained in an eligibility application and who this information must be transferred to. No programs had application fees for sellers to gain eligibility or other rules related to allocation of costs and benefits specific to establishing eligibility.

These results help to contextualize QCA results. Position rules were present in some effective cases and absent in others. According to the QCA results, we expect two configurations of rules when position rules were present in effective programs. First, position, payoff and choice rules all present in the same action situation. Of the eight effective programs, this was the case for only one in both the buyer and seller eligibility action situations. One additional program showed this relationship in the buyer, but not the seller action situation. The other configuration was that position rules were present, but choice and payoff rules were both absent. This combination was found in only one program. The third configuration identified by QCA was the presence of payoff rules when position and choice rules were absent. This configuration was not found amongst buyer and seller eligibility action situations. The most common configuration, present in eight cases was the presence of both position and choice rules and the absence of payoff rules.

4. Discussion

This research sought to apply QCA methods to the institutional arrangements of water quality trading PES programs to determine the utility of the approach for increasing understanding of the relationship of the structure of institutional arrangements and program effectiveness. This was accomplished by testing basic hypotheses using QCA: that certain combinations of rules are found in effective but not ineffective programs, and that these combinations of rules can be identified in individual action situations. The results show that it is possible to identify a general set of rules that is associated with effective programs, but this set of rules is not consistently reflected in individual action situations. In addition, though it was possible to identify a set of rules associated with effective programs, it is unclear if this set is meaningful in understanding program effectiveness.

4.1 Assessing QCA results

The QCA results pointed to three rule configurations associated with effective programs (Table 4). However, when examining these three sets, their usefulness for understanding the institutional arrangements of water quality trading programs appears limited. The three configurations point only to the need for some combination of position, payoff, and choice rules. This is consistent with expectations from PES theory, but not that useful for understanding what types of rules are of particular importance. Though position rules are important in two configurations, they are not needed in the third. So long as payoff rules are present, a program can manage without explicit position rules. And while there are effective programs with position, choice, and payoff rules, the presence of all or even two of these rule types is not necessary for effectiveness. There is little here to enable the analyst with make meaningful recommendations to practitioners seeking to design an effective program.

This becomes more apparent when looking within individual action situations. Of the two action situations evaluated across 8 effective programs, 16 total action situations, the configurations identified in the QCA analysis were present in only 3. In contrast, a different configuration was present in half of the action situations.

Together, these findings indicate that the use of QCA at this very generalized level of analysis may not yield results useful for informing the design of PES institutions. This analysis applied the PES rules classification system from Lien et al., 2018 at its most general level—general rule categories. The logic of conducting the analysis at this level was two-fold. First, the goal was to develop broadly generalizable parsimonious results. As more specific rule types and functions are used in analysis, the more specific the results may become to the specific cases under study. Rules in general, including those for PES program, are idiosyncratic and specialized to the community where an institution is found (Ostrom, 2005). These rules are shaped by the preferences of the individuals that make them, the participants in an institution over time, and the biophysical attributes of the ecosystem where the institution is implemented (Ostrom, 2005; Ostrom, 1990). Therefore, conducting research at the highest possible level of analysis may help to increase the generalizability of results by avoiding case-specific detail.

Second, conducting analysis at a high level is better suited to QCA. For each new variable added to a QCA analysis a new binary combination is also added, exponentially increasing the number of possible combinations of rules. If too many variables are included, explanatory power will soon be lost and the analysis will simply result in each case having its own configuration of rules (Berg-Schlosser et al., 2009). While at the highest level there are only seven rule types, as one steps down to second and third-tier variables, the number of rules expands rapidly.

4.2 Alternatives to QCA

If QCA does not provide a clear way forward for structured comparative analysis of PES programs, what are other alternatives may help analysts develop improved generalizable knowledge and theory about why some PES programs are effective, while others are ineffective? As noted in the introduction, small-n comparative case studies are one approach. A second option is to compare moderate-n sets of cases, perhaps using QCA, at the action situation level rather than the program level.

Small-n case studies are capable of developing deep knowledge and causal explanations about the outcomes of a single or small set of programs. In addition, small-n approaches make evaluation of effectiveness across multiple dimensions—economic, equity, and ecologic—reasonable. In order to build knowledge using case study approaches, however, there is a need for consistent application of theory and methods. Approaches grounded in the IAD and related tools have been suggested as one way of achieving this goal (Meyer et al., 2018; Bennett and Gosnell, 2015) . Overtime, as more case studies using consistent methodology, theory, and framework become available in the literature, meta-analysis may be used to build generalizable knowledge (Poteete et al., 2010). Intensive case study research, however, requires a significant commitment of time and resources.

Institutional analysis across larger sets of PES programs could allow for more rapid accumulation of knowledge. The IAD rules typology and the IGT provide an accessible means for identifying networks of action situations and outcomes within individual PES programs and zooming in to individual action situations to model how rules structure outcomes (Carter et al., 2016; McGinnis, 2011; McGinnis, 2010). When conducted for multiple programs that share certain characteristics, e.g. ecosystem service of interest, similar community attributes, common constitutional or collective choice rules, it may become possible to begin to identify common structures in the network of actions situations or in the collections of rules that shape actor's behaviors within action situations.

The PES rules classification system developed in Lien et al., 2018 provides a starting point for this work. The classification system can be used to guide rapid classification of rules by type and function. Instead of coding entire rule statements according to the IGT, analysts can more quickly assign rules to functions within PES institutions by first identifying the type of rule and then locating the rule by function among the second and third-tier variables in the rules classification system. Using these generalized rule functions allows for more direct comparison across programs while still retaining information about the type and purpose of the rule. This may also enable application of QCA to specific action situations, a potentially more fruitful avenue than its application at the first-tier variable level.

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